PB86-118882

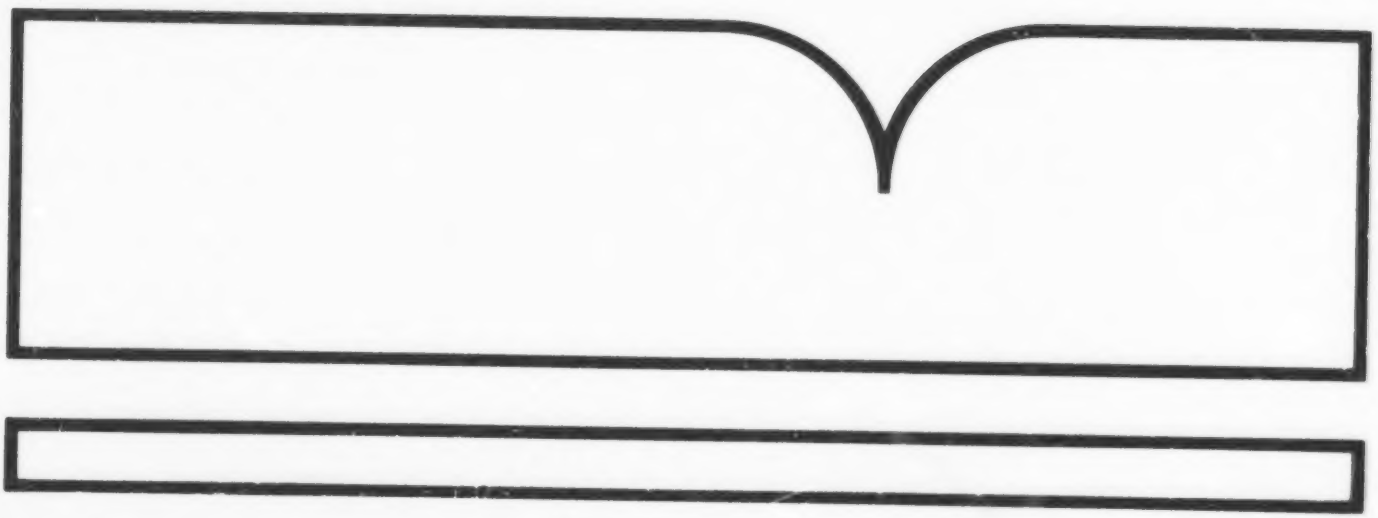
Evaluation of Erosion Feed Chlorinators

(U.S.) Forest Service, San Dimas, CA

Prepared for

Environmental Protection Agency, Cincinnati, OH

Oct 85



U.S. Department of Commerce
National Technical Information Service
NTIS

PB86-116882

EPA/600/2-85/126
October 1985

EVALUATION OF EROSION FEED CHLORINATORS

by

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Interagency Agreement AD-12-F-2-A201

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TECHNICAL REPORT DATA *(Please read Instructions on the reverse before completing)*		
1. REPORT NO. EPA/600/2-85/126	2.	3. RECIPIENT'S ACCESSION NO. PB86 118882/AS
4. TITLE AND SUBTITLE Evaluation of Erosion Feed Chlorinators		5. REPORT DATE October 1985 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Kenneth E. Olson		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Department of Agriculture - Forest Service San Dimas, CA 91773		10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO. AD-12-F-2-A201
12. SPONSORING AGENCY NAME AND ADDRESS Water Engineering Research Laboratory-Cincinnati, OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, OH 45268		13. TYPE OF REPORT AND PERIOD COVERED Final 1/83 to 2/84 14. SPONSORING AGENCY CODE EPA/600/14
15. SUPPLEMENTARY NOTES Project Officer: Gary S. Logsdon, (513)684-7345		

16. ABSTRACT

Erosion chlorinators were evaluated to determine their reliability in delivering a constant chlorine dose for disinfecting potable water sources. Several erosion chlorinators are on the market, but only one has been approved for use with potable water systems in the United States.

The erosion chlorinator was shown to provide unstable dose rates when operated in a continuous-flow mode. Intermittent flow operation provided a more stable dose rate, but the greatest degree of dose stability resulted from a flow rate of 40 gpm, with operating periods of 10 minutes on and 10 minutes off. The use of erosion chlorinators should therefore be limited to intermittent operation.

Additional investigations should be conducted to determine the behavior of the tablets used in the chlorination process. Studies should include calcium deposition, moisture-induced variation in tablet erosion rates, and other characteristics that might affect tablet performance.

17. KEY WORDS AND DOCUMENT ANALYSIS		
a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS *(This Report)* UNCLASSIFIED 20. SECURITY CLASS *(This page)* UNCLASSIFIED	21. NO. OF PAGES 48 22. PRICE

EPA Form 2220-1 (9-73)

DISCLAIMER

The information in this document has been funded wholly or in part by the United States Environmental Protection Agency under Interagency Agreement No. AD-12-F-2-A201 to the United States Department of Agriculture–Forest Service. It has been subject to the Agency's peer and administrative review, and it has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

FOREWORD

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water systems. Under a mandate of national environmental laws, the agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. The Clean Water Act, the Safe Drinking Water Act, and the Toxics Substances Control Act are three of the major congressional laws that provide the framework for restoring and maintaining the integrity of our Nation's water, for preserving and enhancing the water we drink, and for protecting the environment from toxic substances. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Water Engineering Research Laboratory is that component of EPA's Research and Development program concerned with preventing, treating, and managing municipal wastewater discharges; establishing practices to control and remove contaminants from drinking water and to prevent its deterioration during storage and distribution; and assessing the nature and controllability of releases of toxic substances to the air, water, and land from manufacturing processes and subsequent product uses. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

The reliability of erosion chlorinators was evaluated under this project to determine if a constant chlorine dose would be delivered under certain conditions and to evaluate their overall performance and operation. The erosion chlorinators were unreliable under continuous water flow conditions in that unstable doses were delivered. Under intermittent flow, a more stable dose was provided. The greatest degree of dose stability resulted with on-off operating cycles at a flow rate of 40 gpm.

Francis T. Mayo, Director
Water Engineering Research Laboratory

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Erosion chlorinators were evaluated to determine their reliability in delivering a constant chlorine dose for disinfecting potable water sources. Several erosion chlorinators are on the market, but only one has been approved for use with potable water systems in the United States.

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This report was submitted in fulfillment of Interagency Agreement No. AD-12-F-2-A201 by the U.S. Department of Agriculture–Forest Service under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period from January 1, 1983 to February 15, 1984, and work was completed as of September 30, 1983.

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SECTION 1

INTRODUCTION

BACKGROUND

Throughout history, potable water systems have provided highways for the spread of disease. Once introduced, pathogens (disease organisms) can be distributed throughout a water system and result in a widespread outbreak of disease. Historically, a major cause of water-system contamination has been from sewage systems. This relationship was firmly established in 1854, when an outbreak of cholera was traced to a well that had been contaminated from a damaged sewer. Although construction materials and techniques have improved, the potential for damaged or faulty water and sewer lines will always be present, as will the potential for contamination. Also, pathogens can be introduced into a water system at the source of supply, be it surface or ground waters.

By their nature, surface waters are subject to contamination from many sources. Throughout the development of the United States, the primary source of pathogen contamination has been sewage discharges from communities along rivers and lakes. Today, additional contamination sources are present. Many water supply reservoirs, lakes, and streams are used for public recreation and are subjected to body contact activities. The introduction of pathogens into surface waters can also result from the numerous activities associated with the development of adjoining lands. When surface waters are used to supply potable water systems, disinfection must be provided to protect the user.

Although ground waters are generally considered pathogen free and disinfection is not required by some regulatory authorities, contamination can occur in the distribution system or at the well. Pathogens can be introduced into the well from improper or faulty well seals, the proximity of septic tanks, sewer systems, and a host of other sources or activities. The use of ground water does not preclude the need to provide disinfection.

Disinfection is an essential barrier to the transmission of pathogens in a potable water system. Disinfection agents available for use include ultraviolet light, ozone, iodine, chlorine dioxide, and chlorine. Of the agents available, chlorine is the most widely used, chlorine may be supplied as a powder (calcium hypochlorite, or $Ca(OCl)_2$), and commonly as an elemental gas (Cl_2).

Chlorine (as chlorinated lime) was first used sporadically in the late 1800's for emergency disinfection, generally after a water system was contaminated. Routine chlorination did not begin in the United States until about World War I. Manufacturing improvements led to the production of calcium hypochlorite for use in municipal water treatment works. Additional development efforts resulted in the use of gaseous chlorine, which proved easier and less costly for municipal systems. The development of chlorination and disinfection technology has generally followed the development and operation of municipal water systems. Today, most chlorination practices are geared toward the large municipal water system. Application of

municipal practices may not be efficient or effective for the small water system.

The small water system may be characterized as one that has low flows (less than 100,000 gallons per day, and often much less), is operated by a small community, group of individuals, or a business providing water as only a part of their service to the public. In some circumstances, these systems may be designated as small water systems under Federal or State Safe Drinking Water Act regulations. The need to provide disinfection may be regulated under law, or merely be desirable for user protection. In any case, the selection of equipment and practice may be primarily governed by finances, operator availability, and skill. For the large water system, the use of gaseous chlorine is an effective and economical practice. However, its use in a small water system may be costly and ineffective. Small (150-lb) gas containers can be costly to deliver if the use point is out of the normal delivery area. In addition, the cost of safety requirements may be expensive. Many small system operators are reluctant to use gaseous chlorine because of potential safety hazards and the expense of safety equipment. Although easy to use, improper equipment, lack of technical knowledge, or mishandling can cause ineffective treatment.

The alternative to gas has been calcium hypochlorite. However, this agent is not without disadvantages. Storage and handling can be a problem, especially to those without the proper training and experience. The material must be stored carefully. Improper storage or mishandling can cause spills and leakage of chlorine gas, which in turn can lead to corrosion of equipment and other material exposed to the gas or calcium hypochlorite dust and powder. The presence of certain chemicals can result in hazardous reactions. Preparation of stock solutions for the hypochlorinator reservoir exposes the operator to hazards. Caustic dust can cause irritation and burns to the skin and sensitive membranes of the nose, mouth, and eyes. Mixing stock solutions also requires some technical knowledge, as does the operation and setting of the metering pump. Errors in these tasks can result in inadequate disinfection.

Another alternative is the erosion feed chlorinator, which provides advantages over gas chlorinators and hypochlorinators. The use of tablets reduces operator exposure to caustic chlorine dust. Handling and storage of the tablets is safer and easier than gas or powder. Safety equipment is not required, and the operation of the chlorinator does not require as much technical knowledge. The capabilities of the erosion feed chlorinator, however, must be determined.

This project was undertaken to evaluate the reliability of erosion chlorinators to deliver a constant chlorine dose under determined conditions and to evalute their overall performance and operation in the laboratory and the field.

EROSION FEED CHLORINATORS

Erosion feed chlorinators use pressed chlorine tablets that are eroded (or dissolved) as water passes over their surface. The unit generally consists of a canister of some type that stores a supply of tablets and positions them in a moving stream of water. A contact chamber provides an interface between the tablets and water at which point chlorine is introduced. Adjustments of the chlorine dose rate are made by changing the tablet surface area immersed in the water stream. Presently, there is one erosion feed chlorinator marketed for potable water systems, the Water Sure chlorinator (in two models), manufactured by World Water Resources, Rockville, Maryland.

The Water Sure chlorinator uses a calcium hypochlorite tablet manufactured by Olin Corporation, Stamford, Connecticut. These ovoid tablets are approximately 1.2 in. long, 0.8 in. wide, and 0.5 in. thick with a weight of about 0.26 oz. each. The available chlorine is about 65 percent by weight. The tablets are stored in a tapered canister that is threaded into

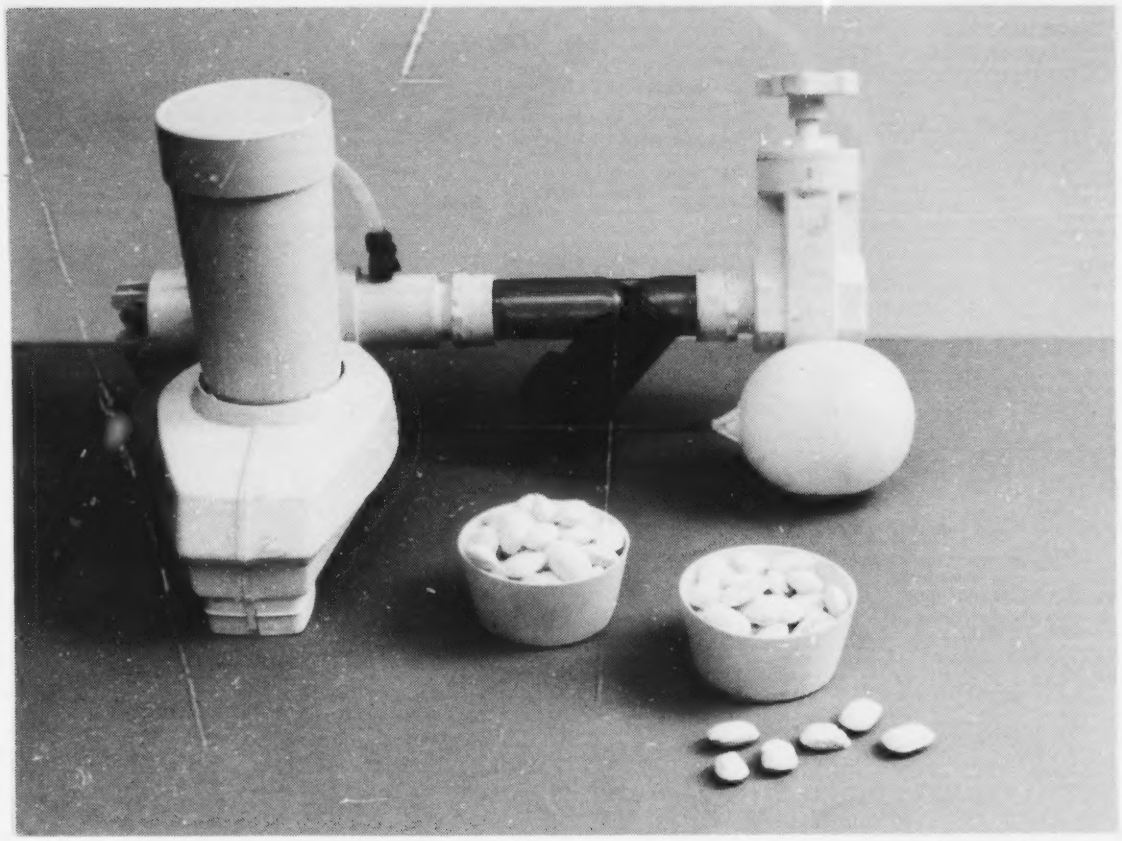

Figure 1. One of several erosion chlorinators with calcium hypochlorite tablets.

the mixing chamber. Adjustment of the canister up or down controls the amount of chlorine dispensed. The Model 050 chlorinator works on a siphon principle. The Model 101 (shown in Figure 1) is designed to operate in a pressure system and controls water flow with a float valve. Both Water Sure chlorinators are gravity-flow units, do not require a power source, and are designed for intermittent flow. The manufacturer does not recommend continuous flow operation. An air break in the water line is required and can usually be provided at a contact chamber or storage tank.

An erosion feed chlorinator that has received approval for use in potable water systems in England is the Sanuril (four models), manufactured by ELTECH Systems Corporation, Chardon, Ohio, and is marketed in the United States for waste water disinfection. This unit has tubular canisters (two or four) that are inserted into a box-like contact chamber. The tablets sold by ELTECH are calcium hypochlorite (the Sanuril 110), with a diameter of approximately 2.6 in., a thickness of 0.8 in., and a weight of about 4.5 oz.

Other erosion feed chlorinators are available, but their uses are primarily associated with swimming pool disinfection. A market search revealed these units generally use a chlorine tablet with cyanuric acid and should not be used for potable water. The chlorine tablet, typically trichloro-s-triazine trione (or tri-chlor) is not approved for use in potable water.

The use of any chlorine agent in potable water is regulated by the U.S. Environmental Protection Agency (EPA). Their approval is the controlling factor for the acceptability of any erosion feed chlorinator for potable water disinfection. Calcium hypochlorite has been approved for use. Any chlorine products not having such an approval should not be used for potable water. An approval for swimming pool use does not infer that a product is suitable for potable water.

Calcium hypochlorite is available in tablet form from manufacturers and packagers. Olin, ELTECH, and Nippon Soda (in Los Angeles, California) market various sizes of tablets. Packaging companies purchase granular calcium hypochlorite for processing into tablets. The primary manufacturers of calcium hypochlorite in the United States are Olin Corporation, PPG Industries (Pittsburg, Pennsylvania), and Nippon Soda.

SECTION 2

CONCLUSIONS

1. When operated in a continuous-flow mode, erosion chlorinators provided unstable dose rates. Impaired performance resulted from moisture-induced tablet bridging and the apparent formation of calcium deposits on tablets, which interfered with the release of chlorine. The continuous flow of water through the chlorinator caused elevated moisture levels in the tablet supply. Elevated humidities occurring during the test period increased the adverse impacts of moisture.

2. Intermittent flow operation of the erosion chlorinator improved its performance over that with continuous flow. Although dose fluctuations occurred with elevated humidities, the impacts were mitigated by increased flow rates and short off-cycles. The greatest degree of dose stability resulted from a flow rate of 40 gpm, with operating periods of 10 minutes on and 10 minutes off. Reduction of flow and increased off-cycles caused increased dose fluctuations, although long-term average chlorine concentrations generally remained fairly stable.

3. The greatest adverse impact on performance of the chlorinator was moisture in the tablet canister. All operating characteristics encountered during both test phases were attributable to the presence or absence of elevated tablet moisture.

SECTION 3

RECOMMENDATIONS

1. The use of erosion chlorinators should be limited to intermittent operation. System designs should provide for 10-minute-on, 10-minute-off operating cycles. Operating flows below 40 gpm, increased operating cycles, and continuous-flow operation should not be considered until moisture-induced problems can be mitigated.

2. Additional investigations should be conducted to determine the behavior of calcium hypochlorite tablets under various moisture conditions. These investigations should identify changes in tablet composition (e.g., calcium deposition), moisture-induced variations in tablet erosion rates, and other characteristics that may affect tablet performance.

3. Manufacturers should be encouraged to continue development work to reduce the adverse impacts of moisture.

SECTION 4

TEST PROCEDURES

Testing was conducted at the USDA–Forest Service Equipment Development Center, San Dimas, California, in three phases: (1) Constant flow, (2) intermittent flow, and (3) simulated field operation. Also, an evaluation of actual field operations was conducted by sending questionnaires to operators of Water Sure chlorinators located at Forest Service field units. The Water Sure chlorinator was selected for testing purposes since it was the only unit marketed for potable water use. An evaluation of the design of operation of available chlorinators did not reveal significant differences which would affect the outcome of testing and evaluations.

Continuous flow testing was conducted with two models of the Water Sure chlorinator in modified installations. Model 101 was installed without the control float to ensure continuous flow, as was a Y-strainer which restricted the flow rate. The Model 050 installation was truncated. Only the chlorinator head was installed in the test stand. The remainder of the parts were not needed for testing but were used to connect a siphon tank. Four flow rates (7, 15, 25, and 40 gpm) and two chlorine dose rates (1 and 5 mg/L) were used to evaluate performance.

Two flow/dose rate combinations were tested simultaneously for 4 consecutive days. Chlorine analyses were performed at alternating 10-minute intervals. Different dose settings identified data on the strip chart used to record free chlorine concentrations occurring during testing.

Intermittent flow testing was conducted with the Model 050 chlorinator. A solenoid valve was installed upstream at the chlorinator to interrupt the water flow for desired intervals (10, 30, and 60 minutes). The desired flow interval, or on-cycle, was determined at the beginning of this test phase. Free chlorine residuals were measured during each on-cycle. During the interrupted flow periods, or off-cycle, chlorinated municipal water was passed through the chlorine analyzer to maintain its sensitivity and calibration. The two water flows were controlled with solenoid valves to prevent mixing.

Free chlorine concentrations were measured with a continuous amperometric analyzer, and recorded on a strip chart. Millivolt values on the chart were translated to concentration value (mg/L), using calibration curves established after each analyzer start-up. Grab samples obtained from the test stand were analyzed with an amperometric titrator and compared to the millivolt reading at the time of sampling. The accuracy of the instruments was checked at the beginning of, and periodically during, testing with known solutions of calcium hypochlorite. These known solutions were analyzed with the titrator and run through the analyzer.

Known solutions were prepared from a laboratory tested calcium hypochlorite powder. A 1,000-mg/L solution was prepared by mixing the powdered hypochlorite with chlorine free distilled water. This stock solution was used to make known hypochlorite solutions by dilution. The powder was stored in a sealed container to prevent degradation.

Standard Methods, Method 408C (1), were used in the analysis procedures. Laboratory procedures for glassware, etc. are also described in this section.

Evaluation of the chlorinator was conducted by reviewing data patterns for the various test segments and other information collected. Because of the amount of data collected during continuous flow testing, chlorine values for each 10-minute analysis period was averaged to provide a single hour value. Data evaluations were conducted graphically with trend lines calculated for significant data segments. Visual observations of events, tablet characteristics, and related conditions occurring during testing were recorded. Comparisons of individual data segments were used to determine patterns or operating characteristics which might result from varying test parameters. Other related information (i.e., weather, system failures, tablet characteristics, and events occurring during testing) were evaluated to determine their effect on both chlorinator performance and data relevance.

SECTION 5

RESULTS AND DISCUSSIONS

CONTINUOUS FLOW TESTING

During pretest operations of the test stand, difficulties revealed the need to modify procedures. Rather than establish the desired dose rates of 1 and 5 mg/L, the chlorinators were set to provide dose rates at approximately these levels. The resulting concentrations were then monitored as planned, with periodic adjustments made to reestablish the desired dose rates. It was also obvious that additional observations and investigation would be required to determine the reasons for the operating patterns observed. Although data were not collected at this time, observations and events indicated the planned dose rates would be difficult to establish and maintain. When first operated with fresh tablets, the chlorinator achieved a stable dose rate within 4 hours, and could be adjusted as desired. After 2 days,however, chlorine concentrations fluctuated over a wide span and became uncontrollable, especially at the high rate, and tablet bridging occurred frequently. Examination of the chlorinator revealed condensation inside the canister on the lid, walls, and tablets. It was initially thought that moisture caused premature release of chlorine from the tablets, which entered the water stream at an uncontrolled rate. Operating the chlorinator without the lid provided only limited correction of the problem. Consistent dose rates were achieved for a week and tablet bridging was significantly reduced, but fluctuations recurred and the dose settings again became uncontrollable.

During testing (see Figures 2 and 3), visual observations were made of the top layer of tablets in the canister each time fresh tablets were added to the canister. The amount of moisture present on these tablets varied from slight to heavy, depending on the flow rate and the humidity. At a flow rate of 7 gpm, and with a low humidity, the top layer of tablets showed a slight discoloration, but was dry to the touch. This condition was detected after a day's operation and could also have been caused by night time higher humidities. At a flow rate of 40 gpm, with low humidities, discoloration occurred within 3 to 5 hours, and dampness could be detected within 5 to 8 hours. As the humidity increased, the amount of moisture present on the tablets increased significantly. During periods of fog or rain, water droplets 1/16- to 1/8-in . diameter were discovered within 2 to 4 hours after fresh tablets were added to the canister.

Visual inspections of the tablets layered throughout the canister showed that the bottom layer of tablets (1-1½ in.) was saturated. It was within this layer that tablet erosion occurred. Above this erosion zone, moisture present on the tablets was approximately the same as that on the top layer of tablets. While there was an increase in moisture with depth, the difference did not appear significantly different.

Observations made of the water flow within the canister revealed it mostly quiescent (non-turbulent) regardless of the flow rate through the chlorinator or the depth at which the canister was immersed in the water stream. The depth at which the canister was set into the water stream to achieve a desired dose rate depended on the flow rate. At 40 gpm, a 1 mg/L dose rate was achieved with the bottom of the canister at the water surface. Turbulence in the chlorinator

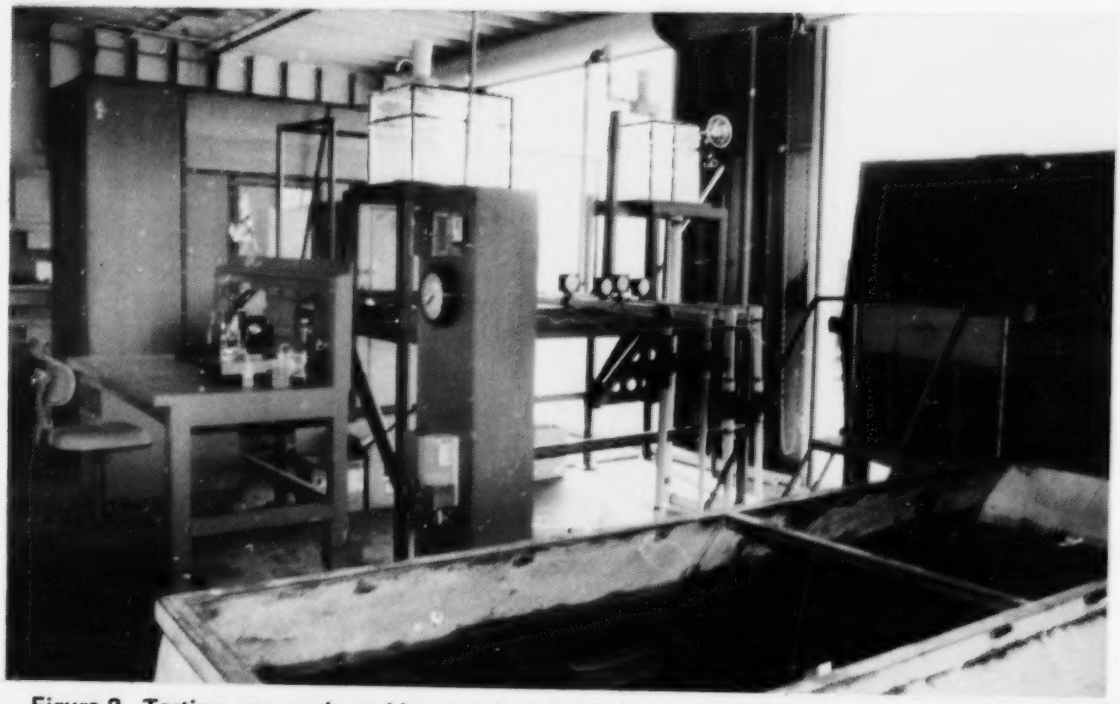

Figure 2. Testing was conducted by pumping dechlorinated water from a reservoir (foreground) to the chlorinators, followed by automatic analysis prior to its return to the reservoir, the water was dechlorinated with activated carbon (middle right).

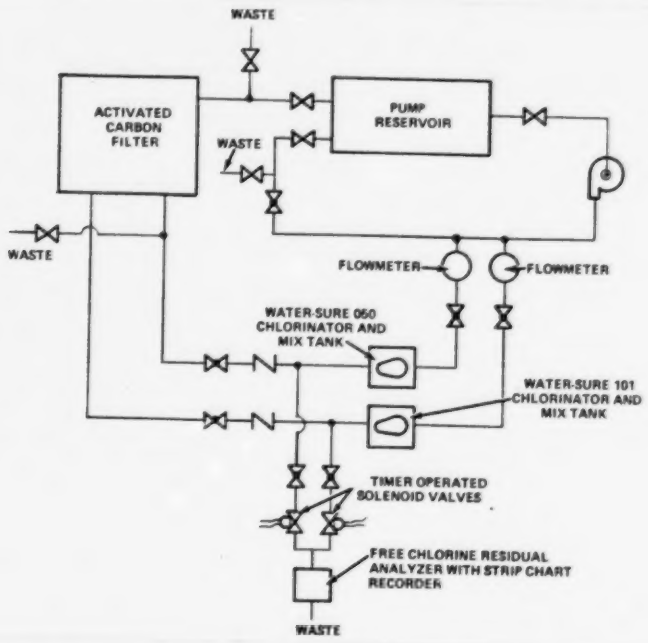

Figure 3. Test stand schematic.

contact chamber caused a fluctuating water surface which lapped into the canister openings, and onto the tablets. At a flow rate of 7 gpm and a dose setting of 5 mg/L, the canister was immersed about ½ in. into the water stream. These conditions represented the extremes encountered during testing. Although the turbulence within the chlorinator body increased with the depth setting of the canister, the flow with the canister itself was generally quiet or nonturbulent. Observations did reveal that turbulence could occur at certain orientations of the canister, and that a jet of water could be directed into the canister. If the side openings of the canister were positioned into the water stream, a small amount of turbulence occurred. A jet of water from the bottom or side openings could occur at any orientation, but was due to the presence of calcium deposits on the canister bottom that caused water to deflect into the canister. A significant amount of turbulence within the canister was noted only when the canister setting was well in excess of that for a dose rate of 5 or even 10 mg/L.

Moisture was a cause of the performance problems encountered during this test phase. However, the initial assumption that uncontrolled dripping of condensation caused fluctuating concentrations could not be substantiated. Periodic examinations of the canister did not reveal any free water present except the previously noted droplets on the top layer of tablets. Moisture present in the canister was absorbed by the tablets. This, in turn, caused tablet bridging and may have contributed to the formation of calcium deposits on the tablets which interfered with the release of chlorine. During testing, tablet bridging was generally associated with high moisture levels. Absorption of moisture by the tablets created a pastelike coating on the tablet surface and also resulted in a swelling of the tablet. A slightly adhesive quality of the paste, the increased tablet size, and the inward taper of the canister caused the tablets to become bonded together. When still wet, the bridge was easily broken by tapping the canister. If drying occurred, however, the tablets were difficult to break. Evaluation of the Water Sure showed that the tapered canister contributed to bridging. In chlorinators with untapered canisters, tablet bridging (or jamming) was reported to occur when swelling caused the tablet to stick in the canister. The general result of a tablet bridge was in interruption of chlorination when the tablet supply below the bridge was depleted. The saturated layer of tablets in erosion zone was not affected by bridging. Along with service interruptions, the occurrence of bridges was detected during testing by tapping the canister and noting any significant settling of the tablets. A settling of about ½ in. was generally due to tablet shifting. Bridges resulted in a settlement of 1 in. or more, usually 1½ to 2 in. Undetected bridges may also have occurred which were broken by the weight of tablets above the bridge, or some disturbance to the chlorinator. One example of this could be the downward spike (6.4 mg/L to 2.4 mg/L on day 2), shown in Figure 4. The chlorine concentration was recovering before tablets were added to the canister and an examination did not reveal the presence of a bridge. While other examples are difficult to isolate at 5 mg/L due to the data patterns, Figures 8, 9, 10, and 11 show similar inverted spikes.

Although tablet bridging was a definite interference, it was not significant in the overall performance of the chlorinators. Of more importance was the apparent deposition of calcium on the tablet surface. Observations of the chlorinator revealed only a portion of the water flows through the contact chamber entered the canister. The amount depended on the depth of the canister in the water stream that varied according to the flow rate and canister adjustment. Conditions within the canister were conducive to the formation of a calcium coating, with a calcium concentration at or above the saturation level. Evaluations of the chlorinator, events occurring during testing, and the environment of the tablets supported this theory. However, tablet analysis could not be performed to confirm this behavior.

A literature search and discussion with various manufacturers was made to locate supporting information, and while those contacted agreed that a tablet behavior as described was probable, test and research data were not available.

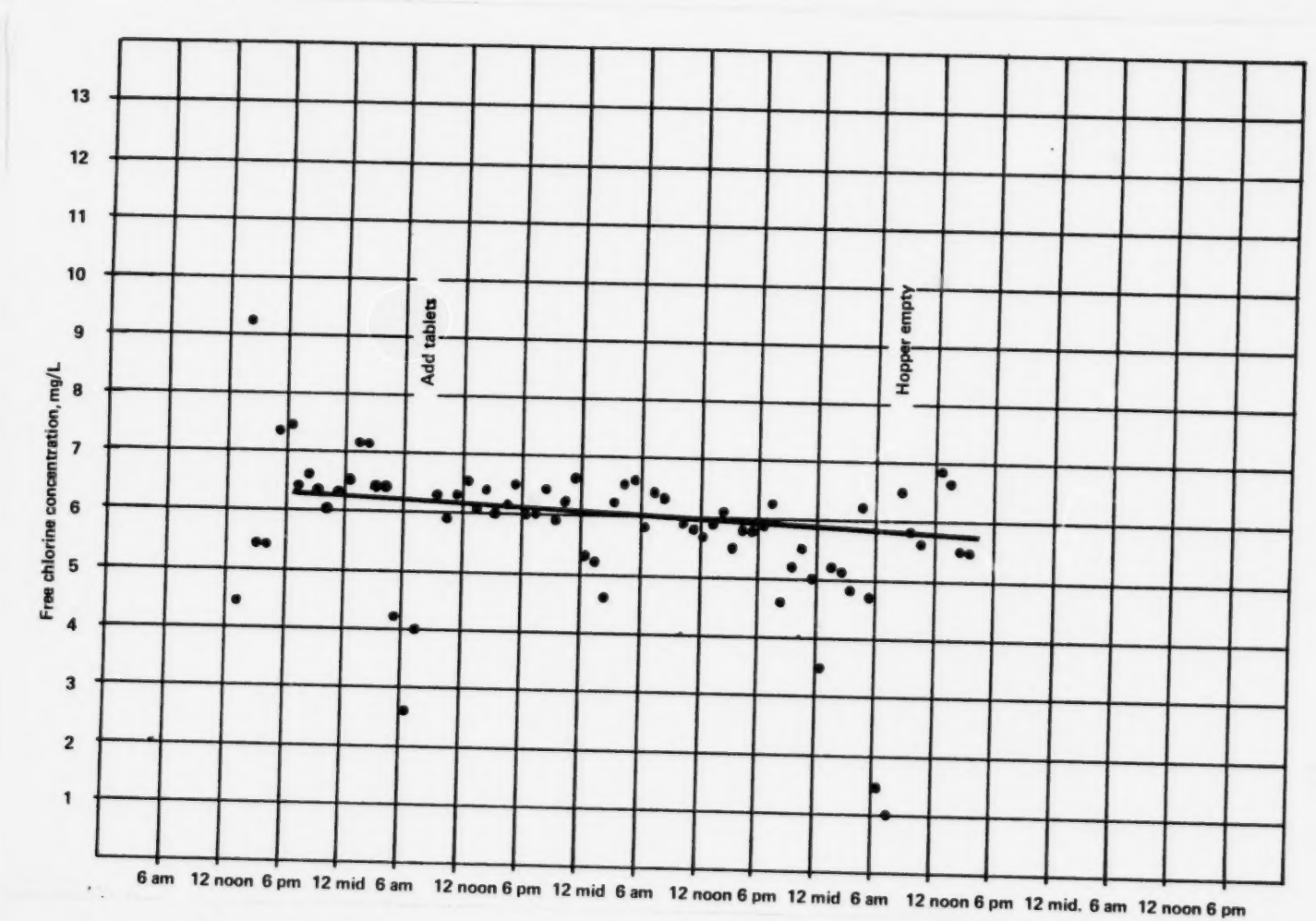

Figure 4. Free chlorine concentrations for continuous flow at 40 gallons per minute and 5 mg/L desired dose rate.

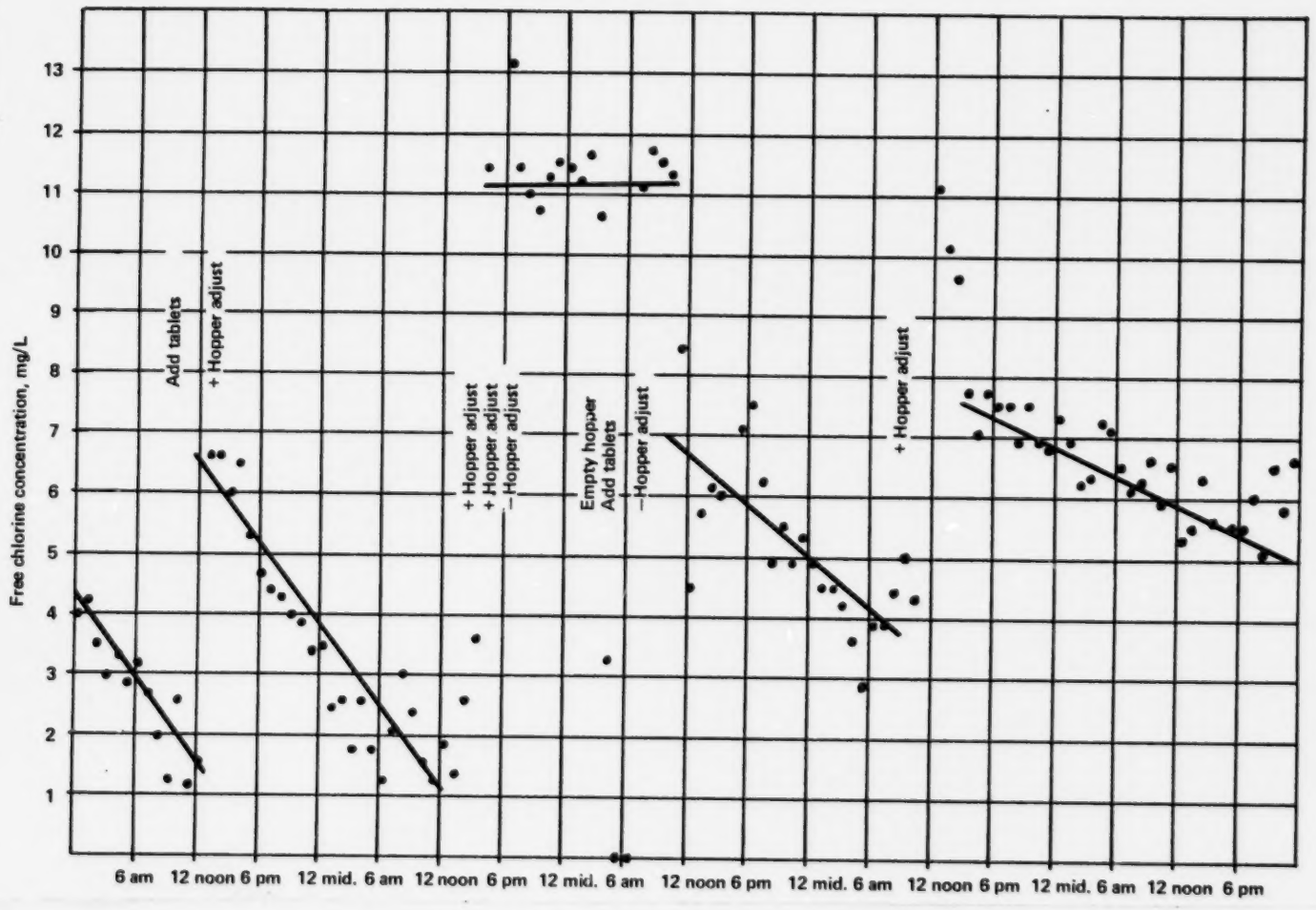

Figure 5. Free chlorine concentrations for continuous flow at 25 gallons per minute and 5 mg/L desired dose rate.

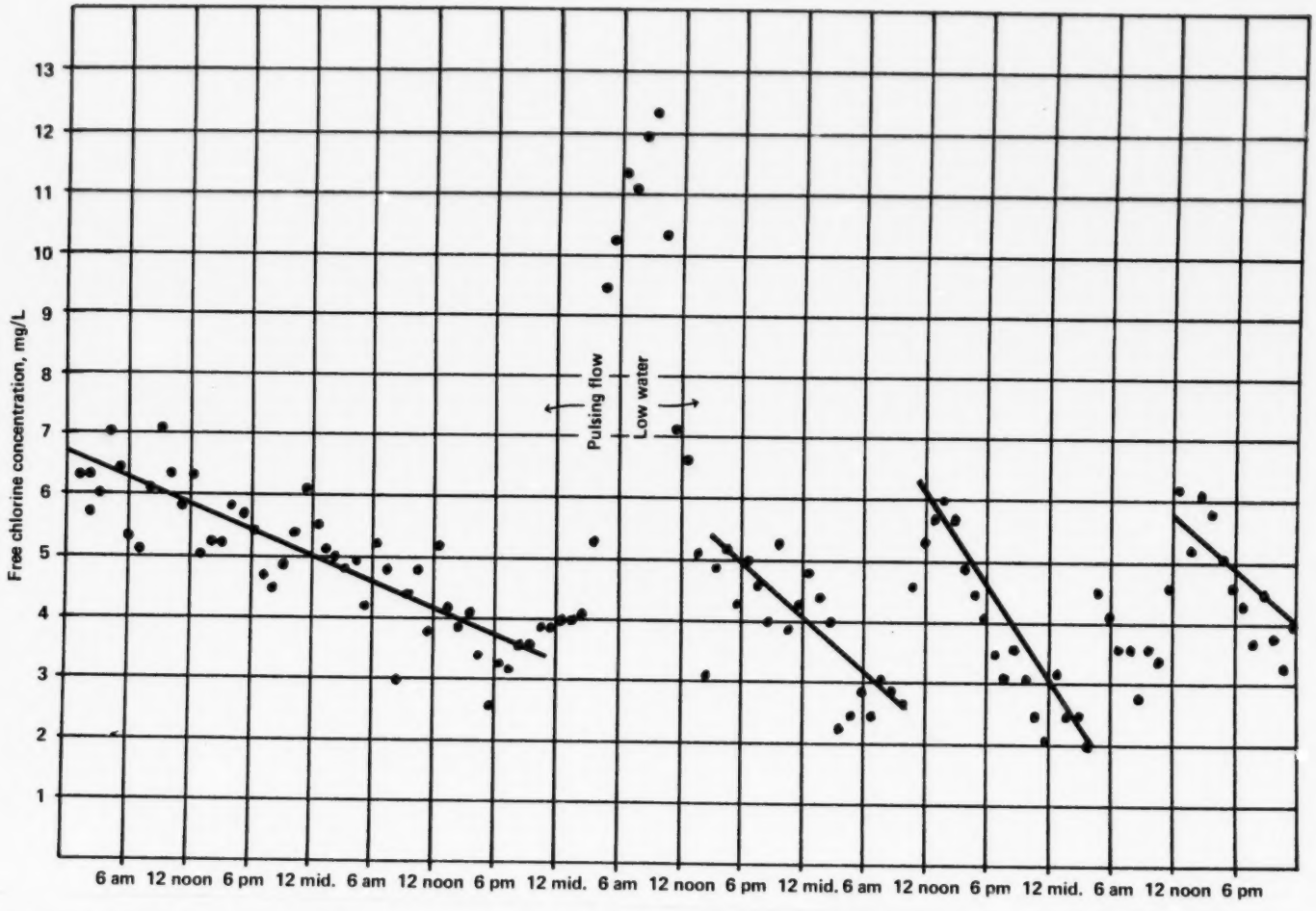

Figure 6. Free chlorine concentrations for continuous flow at 15 gallons per minute and 5 mg/L desired dose rate.

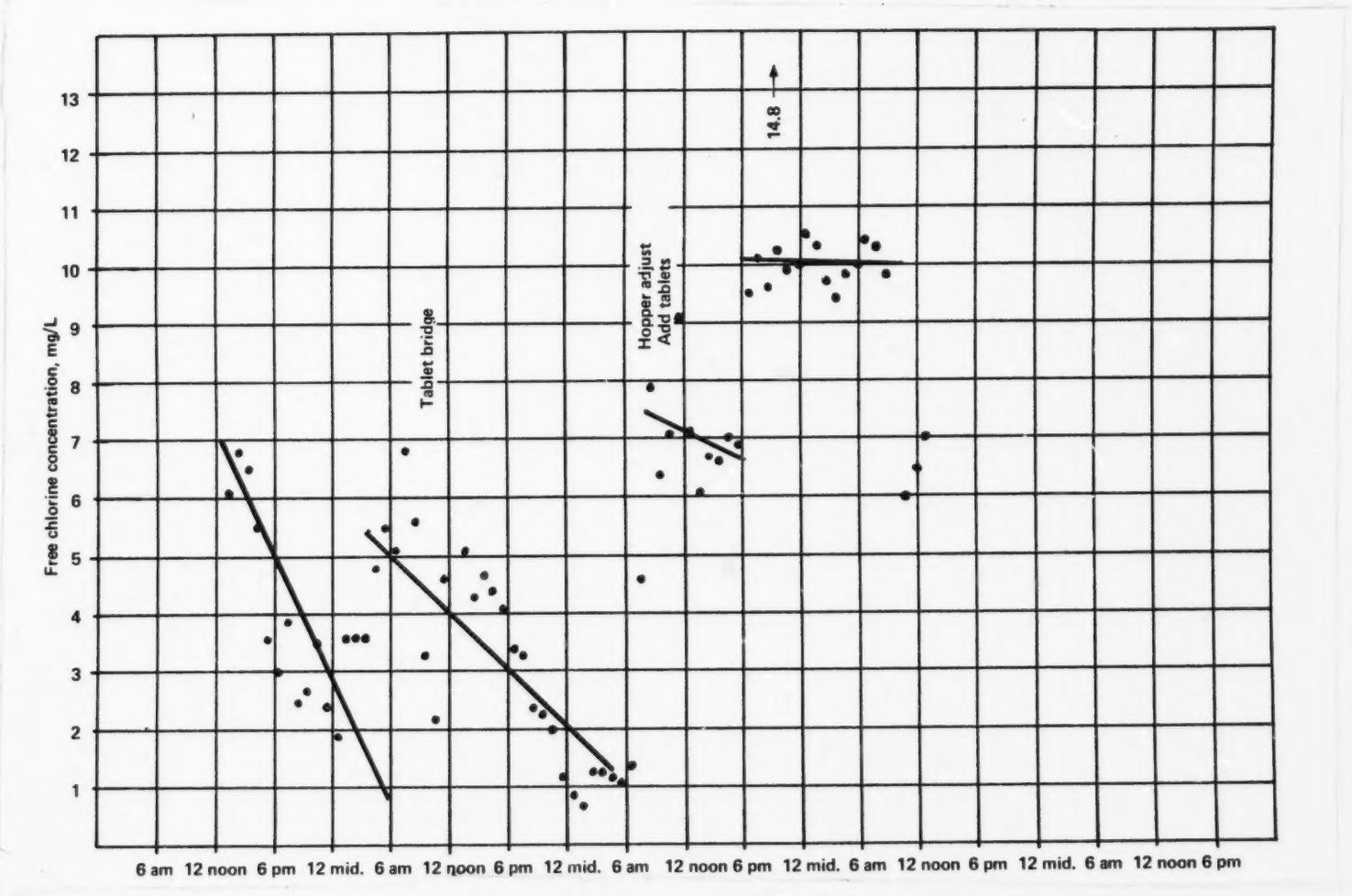

Figure 7. Free chlorine concentrations for continuous flow at 7 gallons per minute and 5 mg/L desired dose rate.

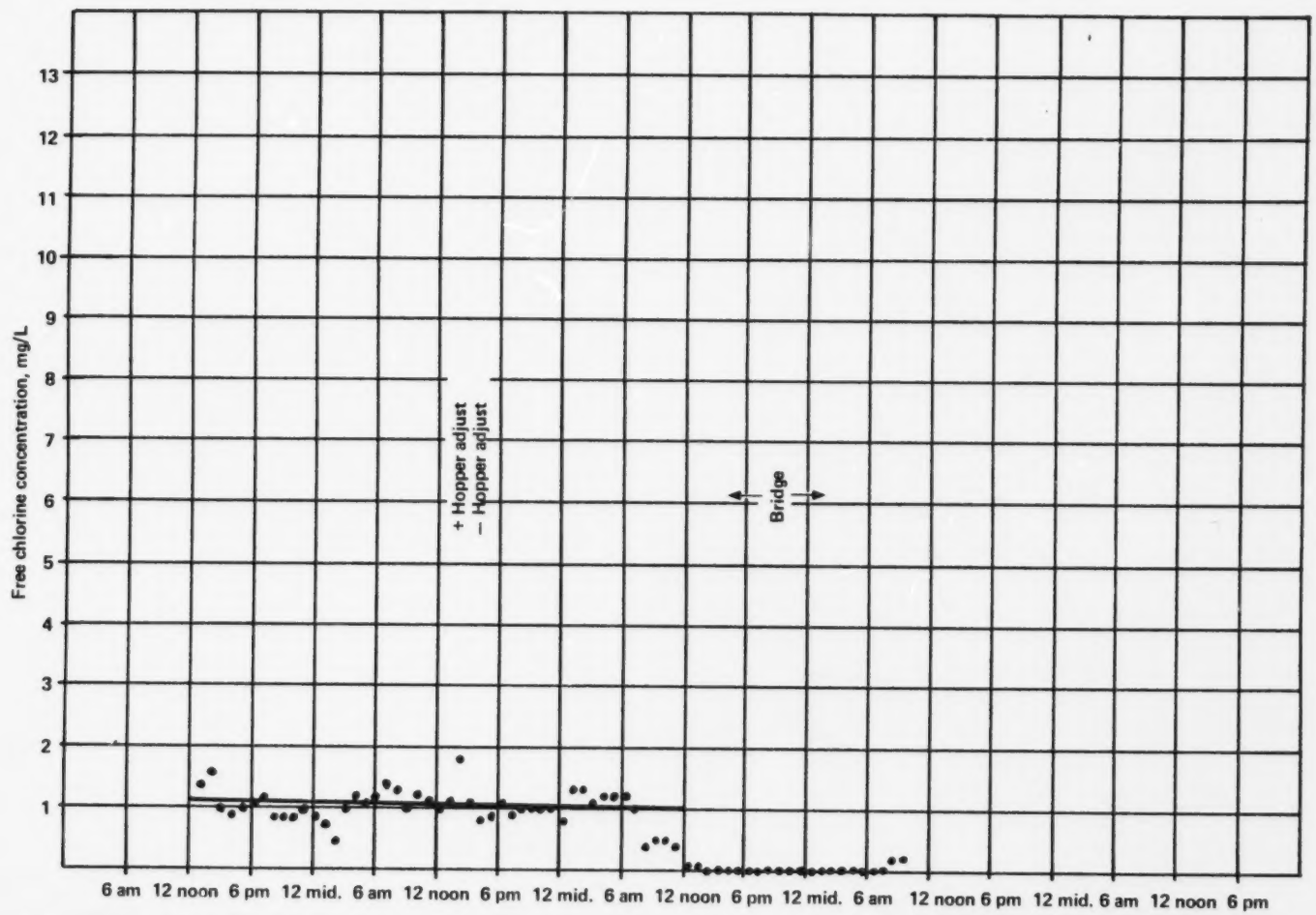

Figure 8. Free chlorine concentrations for continuous flow at 40 gallons per minute and 1 mg/L desired dose rate.

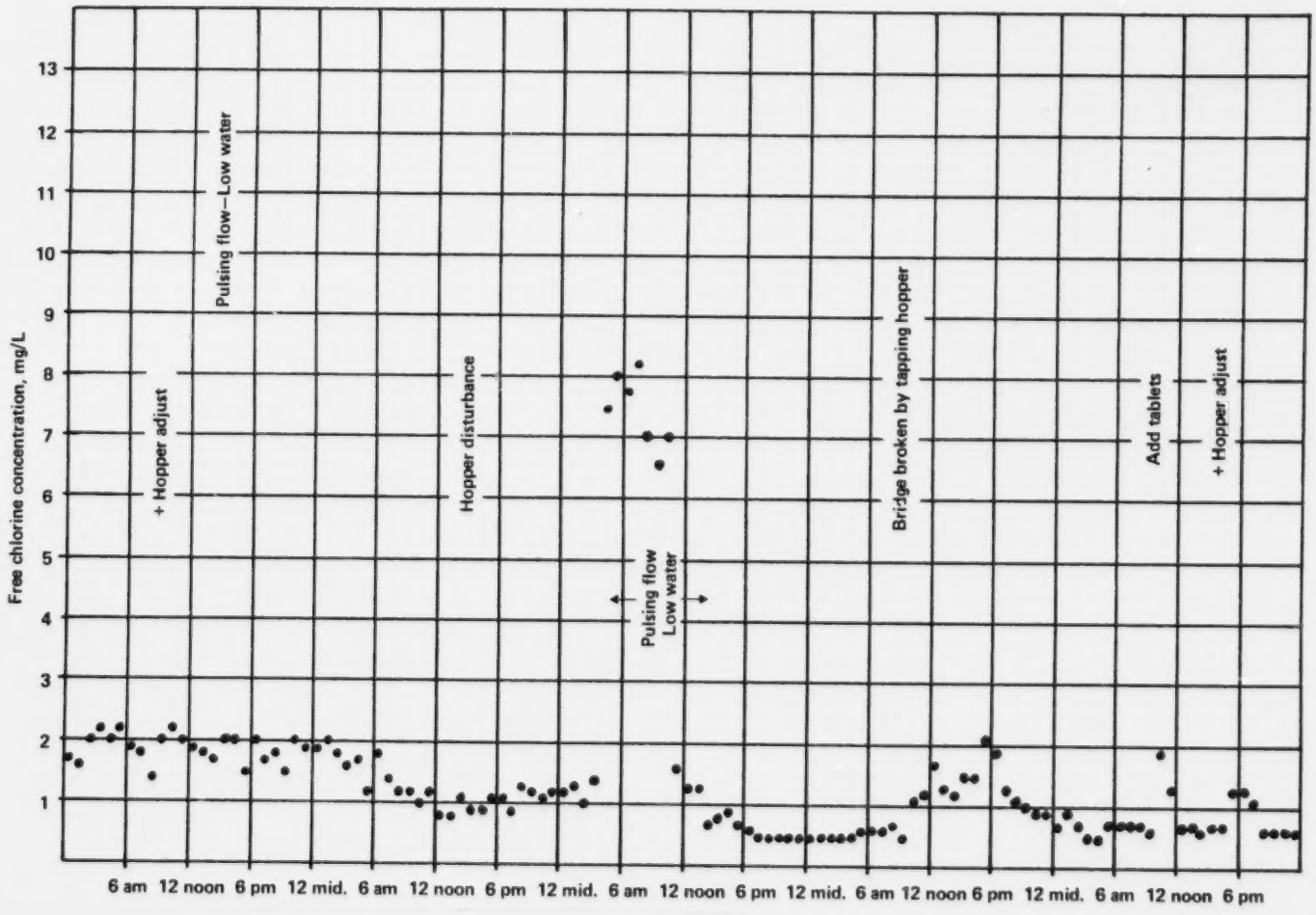

Figure 9. Free chlorine concentrations for continuous flow at 25 gallons per minute and 1 mg/L desired dose rate.

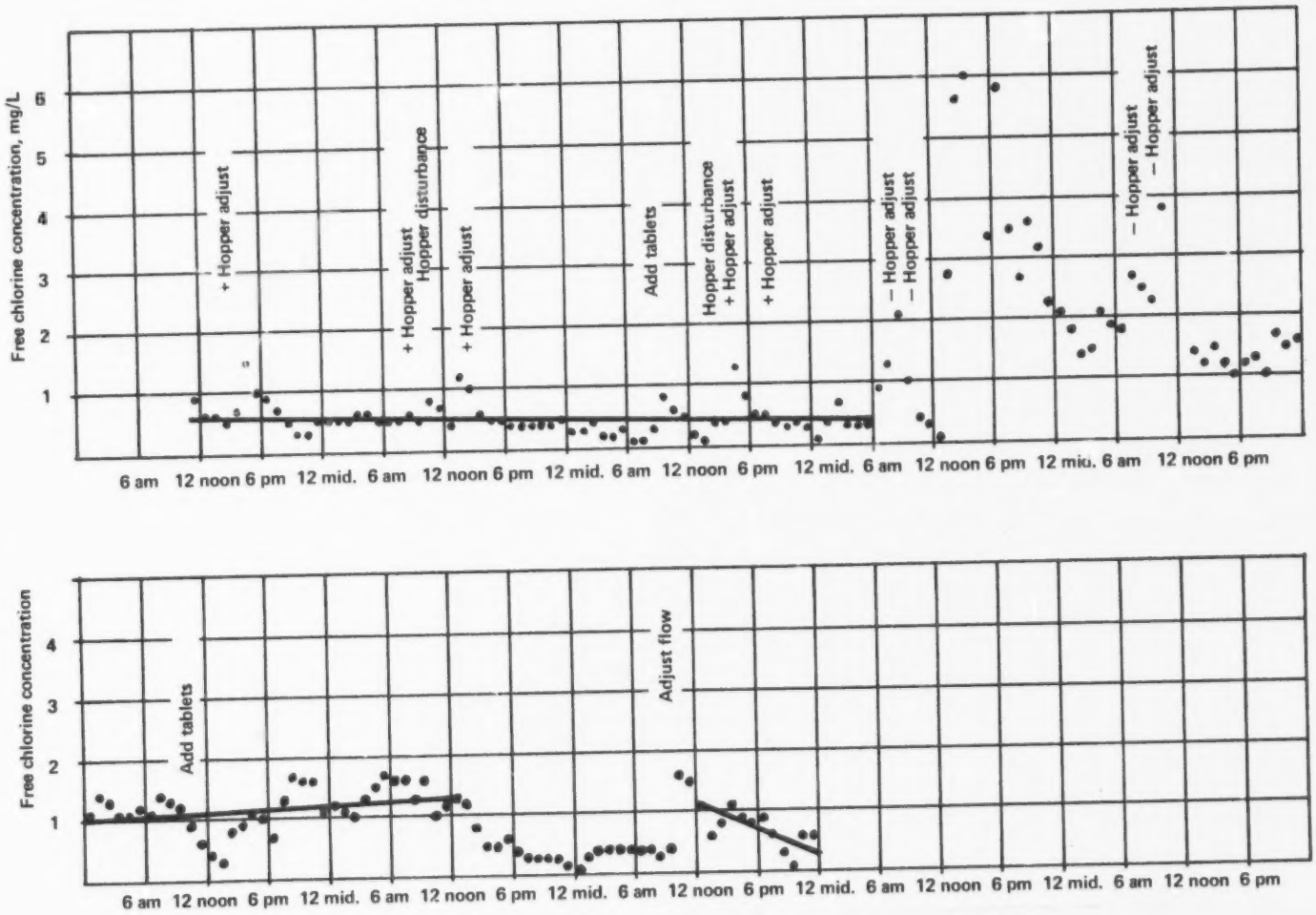
Free chlorine concentration, mg/L
6
5
4
3
2
1
+ Hopper adjust
+ Hopper adjust
Hopper disturbance
+ Hopper adjust
Add tablets
Hopper disturbance
+ Hopper adjust
+ Hopper adjust
– Hopper adjust
– – Hopper adjust
– Hopper adjust
– Hopper adjust
6 am 12 noon 6 pm 12 mid. 6 am 12 noon 6 pm 12 mid. 6 am 12 noon 6 pm 12 mid. 6 am 12 noon 6 pm 12 mid. 6 am 12 noon 6 pm
Free chlorine concentration
4
3
2
1
Add tablets
Adjust flow
6 am 12 noon 6 pm 12 mid. 6 am 12 noon 6 pm 12 mid. 6 am 12 noon 6 pm 12 mid. 6 am 12 noon 6 pm 12 mid. 6 am 12 noon 6 pm

Figure 10. Free chlorine concentrations for continuous flow at 15 gallons per minute and 1 mg/L desired dose rate.

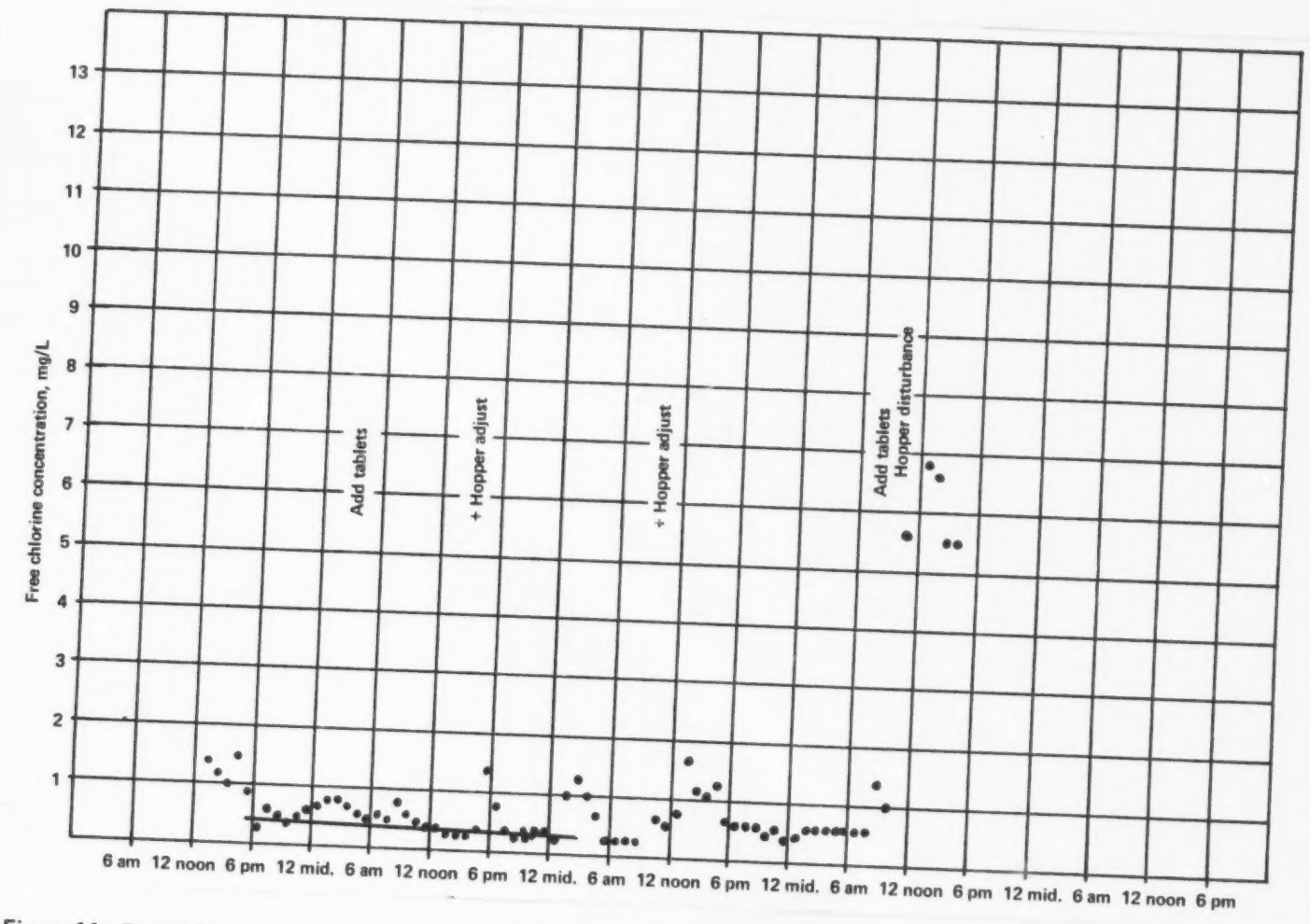

Figure 11. Free chlorine concentrations for continuous flow at 7 gallons per minute and 1 mg/L desired dose rate.

Conditions in the canister and at the tablet surface would be conducive to the formation of a calcium coating. The release of the hypochlorite ion, and its subsequent conversion to hypochlorus acid, allows free calcium ions to combine with available anions. Since the canister is filled with tablets, the water-filled voids would have a calcium concentration at or above the saturation level. This saturation was evidenced by calcium plating around the canister openings, both inside and out. Both calcium deposition and the presence of hypochlorus acid are dependent of pH. However, the formation of a calcium coating on the tablet would occur regardless of the pH value. As the pH increases, calcium will have a greater tendency to precipitate. Lower pH values result in an increased presence of hypochlorus acid, leaving a greater number of free calcium ions to combine with available anions.

As the calcium coating covers the tablet surface, it reduces the exposure of hypochlorite ions to the water flow in the canister. Although the coating is not watertight, it acts as a barrier reducing the amount of water in contact with the calcium hypochlorite surface and restricts the flow of hypochlorite ions from that surface. The continued formation of this barrier would result in decreased chlorine concentrations in the water stream. A periodic sloughing of portions of the barrier would temporarily expose fresh hypochlorite surfaces and cause fluctuating chlorine concentrations.

Several events during testing support the formation of a calcium coating on the tablet. Disturbances to the chlorinator resulted in increased chlorine doses. The magnitude and duration of these increases were dependent on the severity of the disturbance. The addition of tablets, sudden flow rate changes, canister adjustment, and movement of the chlorinator caused chlorine concentrations to increase. The most common disturbance during testing was rapping of the canister to settle tablets or to release a tablet bridge.

Figures 4 through 11 present the data obtained during continuous flow testing. The impact of the calcium is most apparent at the higher dose setting (Figures 4 through 7). The data shown in Figure 4 indicate a relatively stable concentration can be achieved at 40 gpm. This may be due to the water level in the canister. Observations of the water level showed that at 40 gpm, a 5 mg/L dose resulted when the canister bottom was slightly immersed in the water stream. The depth of water in the canister varied from zero to about ¼ in. Turbulence outside the canister caused the water surface in the chlorinator body to fluctuate. The lapping and splashing of water into the canister may have provided sufficient turbulence to remove a portion of the calcium coat. Although the three following figures show cyclic decreasing concentrations, a comparison of the data does not indicate a dose stability related to flow. The data patterns shown in Figures 5, 6, and 7 are similar and do not approach that shown in Figure 4. If there is a flow-related stability, it may not be evident below a certain flow rate, such as 30 or 40 gpm. Additional investigation would be required to determine this.

The data patterns shown in Figures 5, 6, and 7 do show the impact of calcium deposition, sloughing, and redisposition. The formation of the calcium deposits is illustrated by the declining chlorine concentrations occurring after an initial dose setting is established. The addition of tablets, tapping the canister, and canister adjustments were responsible for the major increases shown at the beginning of each data trend line. These activities caused sloughing of the calcium which exposed fresh calcium hypochlorite surfaces. This sloughing was followed by the continued deposition of the calcium. The fluctuations occurring along the trend line were thought to be due to minor sloughing.

Generally, the increased dose rates at the beginning of each trend line were due to canister adjustments and servicing. However, two increases seen in Figure 7 occurred when operators were not present and are unexplained. After establishing an initial concentration on the first day, the chlorine doses declined. The rate of decline should have resulted in a concentration less than

1 mg/L. However, a sharp increase occurred about midnight and again about 4:00 a.m. Another increase occurred on day 3, at about 5:00 a.m. The reason for these events could not be determined, other than a disturbance of some type occurred.

During pretest operation, and once during testing (see Figures 6 and 9), the test stand water supply was lost. In both instances, there was sufficient water to provide a pulsing flow through the chlorinators. The chlorine concentrations increased dramatically. The effect of the water loss can be seen on day 3 at 3:00 a.m. Figure 6 shows chlorine concentrations increasing from about 4 mg/L to about 12 mg/L. Prior to this event, the descending curve illustrates the formation of the calcium layer on the tablet. This layer was removed by the pulsing water flow that rapidly varied between 8 and 12 gpm. The turbulence and splashing of the pulsing flow prevented the reformation of the calcium layer so that a hypochlorite surface was continuously exposed to the water. The increase shown in Figure 9, from about 1 mg/L to about 8 mg/L, resulted from a pulsing flow rate of 15 to 20 gpm.

Although conditions are different at the lower dose setting (this will be discussed later), the same pattern can be seen; a sharp increase in chlorine to about 8 mg/L.

Figure 5 illustrates another event which supports the coating theory. During day 3, an effort was made to maintain a continuous dose rate by adjusting the canister. These adjustments began about 8:00 a.m., and continued into the afternoon without effect. An increase in the concentration occurred at about 2:00 p.m. An adjustment at about 3:00 p.m. resulted in a dramatic increase to about 11.5 mg/L of chlorine. This dose level remained fairly constant through the night until the canister was adjusted on day 4 to reduce the dose rate to desired test levels. The increase in the dose rate was due to an increased depth of the canister into the water stream. This resulted in increased turbulence in the chlorinator contact chamber and an increased flow through the canister. Tablets lying against the canister bottom were exposed to turbulent flow which removed the calcium coating and prevented it from formation. The increased flow through the canister aided in the removal of calcium from the canister. The occurrence of jetting and an ideal orientation of the canister may also have provided turbulence within the canister.

The formation of the calcium coating is critical to the operation of an erosion feed chlorinator, and is dependent of the exposure of the tablets to turbulence. Consistency in the amount of chlorine dosed by the chlorinator was observed under two basic dose settings; high (10 to 12 mg/L), and low (about 1 mg/L). Midrange settings did not provide consistency. The exposure of the tablets to turbulence at high and low dose settings is maximized. At a high dose setting, the canister causes increased turbulence in the chlorinator contact chamber. The amount of turbulence is dependent on the flow rate. At the low dose setting (1 mg/L), the canister was at most only slightly immersed in the water stream at a low flow rate (7 gpm). At the high flow rate (40 gpm), the canister was at or slightly above the mean water surface in the contact chamber. At 40 gpm, only a mijnimal contact between the tablets and the water surface was needed to provide a dose rate of 1 mg/L. The turbulence-caused fluctuations of the water surface in the contact chamber were sufficient to provide this contact. Flow observation showed there was no water flow through the canister at 40 gpm at a canister setting for 1 mg/L. Water contact was provided by the lapping of the flow surface into the canister openings. This lapping provided minimal water-tablet contact, decreasing the formation of a calcium coating, and exposing the tablets to turbulence which was sufficient to remove any calcium formation. The data presented in Figures 8 through 11 show relatively flat data curves with fluctuations generally within a 1 mg/L span.

INTERMITTENT FLOW TESTING

Intermittent flow testing revealed improved chlorinator performance due primarily to the

interruption of water flow through the unit. The ideal conditions for this test phase, as well as for overall operation of the chlorinator, were found to be a flow rate of 40 gpm with an operating period of 10-minutes on, 10-minutes off. Increasing both the on- and off-cycles resulted in greater dose fluctuations, as did reducing the flow rate. The various weather conditions encountered during testing revealed that dose stability was heavily influenced by humidity levels. Erratic chlorine concentrations were observed only during periods of high humidity.

Initial testing during this phase included a determination of an ideal operating period for the chlorinator. The stability of a dose rate was observed for increasing on-cycles of 10 and 20 minutes. At the longer period, chlorine concentrations fluctuated after 10 to 15 minutes and resembled those seen in continuous-flow testing. A 10-minute on-cycle provided dose stability throughout this test phase. The dose rate during individual on-cycles remained within a 0.5 mg/L span, with most cycles showing a virtually constant dose. The greatest fluctuation occurring with a 10-minute on-cycle was about 2 mg/L, but this was infrequent.

Visual inspection of tablets in the canister did not show a significant change in moisture levels attributed to flow rates. With similar humidity conditions, tablet moisture appeared constant. Surface textures, observed visually and by touch, retained the same graininess and pasty feeling. The depth of the moisture, detected by scraping the tablet surface, did not appear to change at the various flow rates. Increased moisture levels were detected only during periods of increased humidity. As moisture levels increased, the tablet surface became grainy and paste-like, but not to the degree observed in continuous-flow testing. Only during periods of heavy rain or fog did water droplets (1/16- to 1/8-in. diameter) occur. The absorption of tablet moisture was primarily governed by humidity levels. However, once absorbed, tablets tended to retain moisture. Anticipated drying of tablets during the different periods of no-flow (off-cycle) were not observed to be significant. Although the tablets were exposed to air for up to 60 minutes, appreciable improvement in the appearance of the tablet surface was not detected. The only improvement noted was the disappearance of water droplets from the top layer of tablets, which could have been due to their absorption by the tablet. The lack of drying during the off-cycles was attributed to the lack of airflow through the chlorinator. Depending on the humidity, drying occurred only when the test stand was shut down for 1 day or more. However, this occasionally resulted in the bonding of tablets. Overall, the tablet moisture observed during intermittent-flow, and higher humidity levels were required to produce similar tablet moisture. Intermittent operation reduced moisture.

Interrupting the water flow through the chlorinator reduced the exposure of tablets to moisture by allowing the erosion zone to drain off free water and to, at least partially, dry. The periodic draining of the erosion zone reduces the migration of water into the upper tablet level by reducing the water-tablet contact time. Also, any free water on the tablet surface just above the erosion zone would have drained and been exposed to air. While tablet drying in the upper level of tablets was not apparent, it did occur in the erosion zone. After a 10-minute off-cycle, the tablets in this zone (1 to 2 in.) had a loose, granular texture which was easily dislodged and could not be measured. Regardless of the flow rate, the same texture was observed. Tablet drying in the erosion zone was attributed to this texture since there was a greater surface area exposed to a larger volume of air. In the upper tablet level, air was present only in the voids between the tablets.

Observations of the chlorinator's operation showed an initial turbulence at the start of each on-cycle which quickly subsided to the quiescent flows observed previously. Fluctuating water surfaces and splashing accompanied the entry of water into the contact chamber. Although the event could not be observed with tablets in the canister, the initial turbulence dislodged the loose tablet surfaces. This was indicated by the presence of tablet residue found in the contact chamber, the mix tank, and the carbon filter. Although residue was found during continuous flow testing,

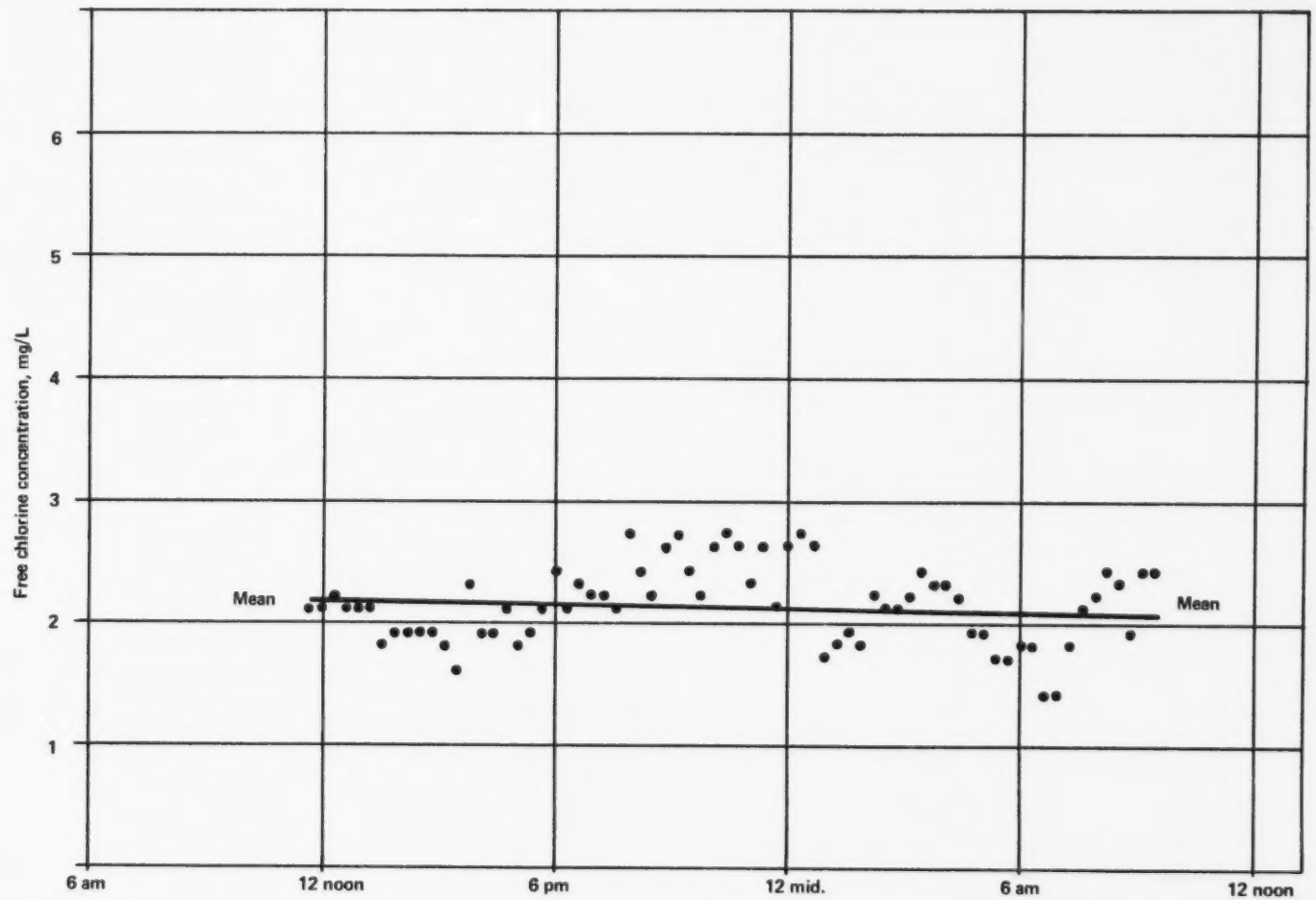

Figure 12. Free chlorine concentrations for intermittent flow at 40 gallons per minute, 10 minutes on, 10 minutes off.

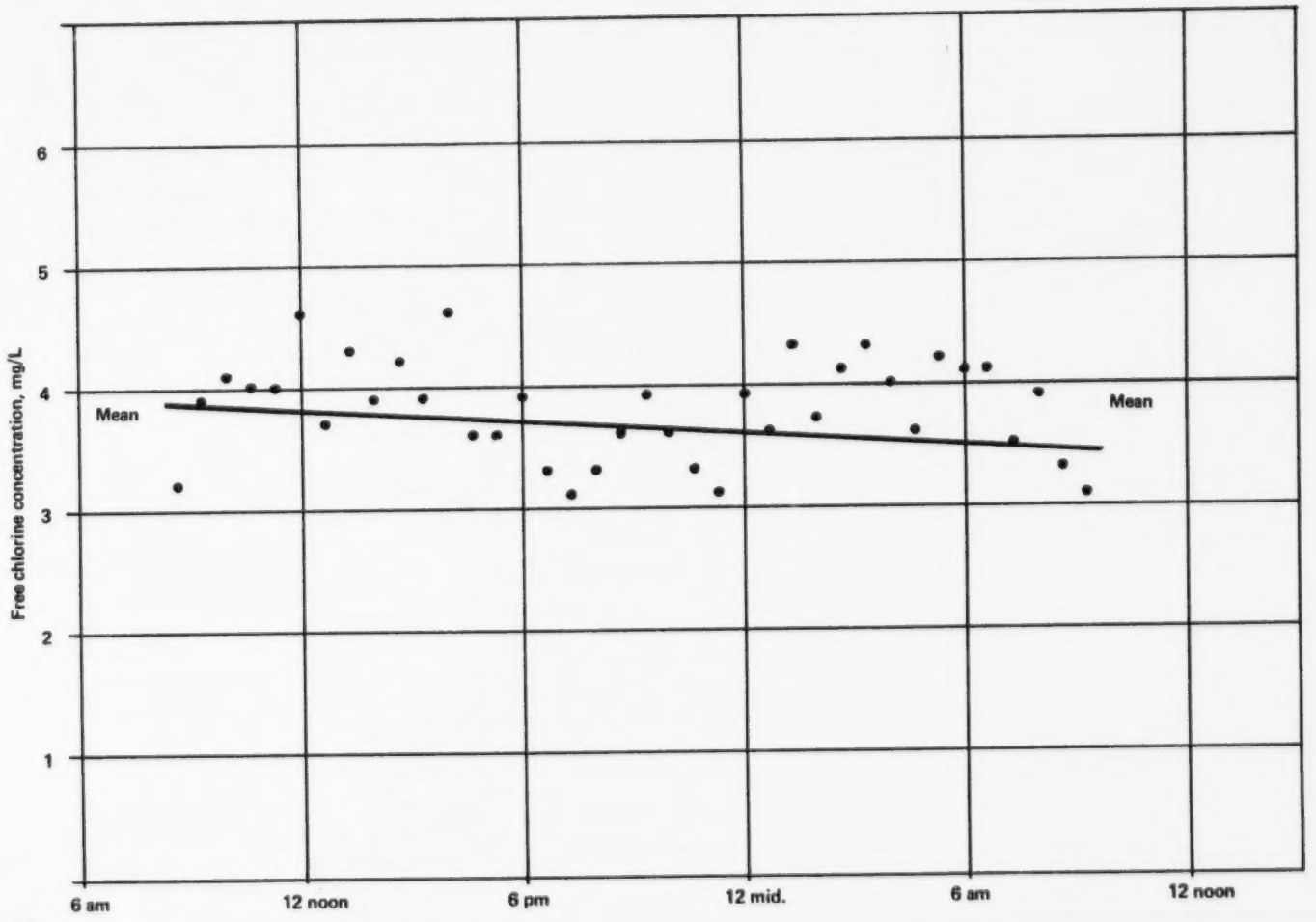

Figure 13. Free chlorine concentrations for intermittent flow at 40 gallons per minute, 10 minutes on, 30 minutes off.

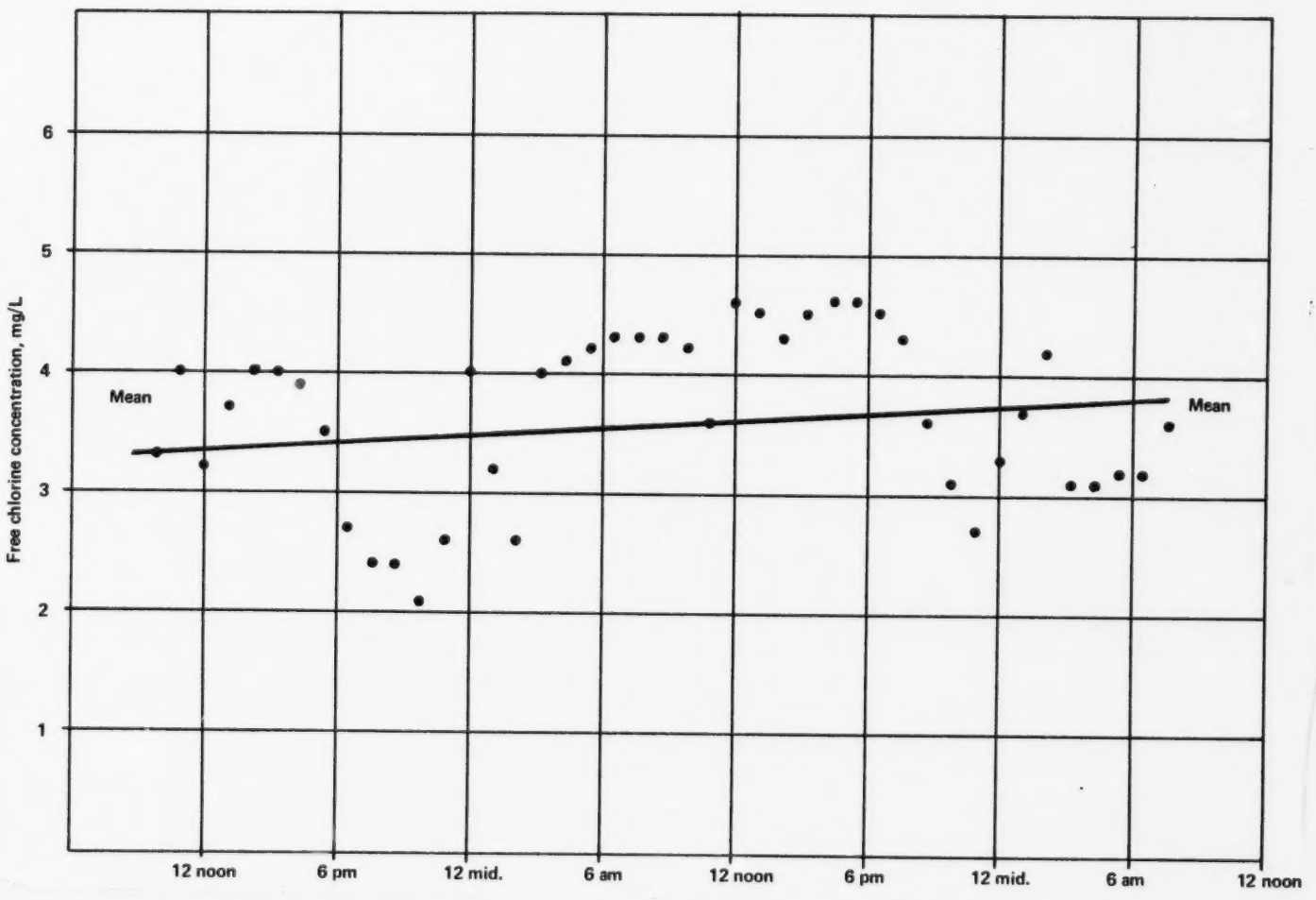

Figure 14. Free chlorine concentrations for intemittent flow at 40 gallons per minute, 10 minutes on, 60 minutes off.

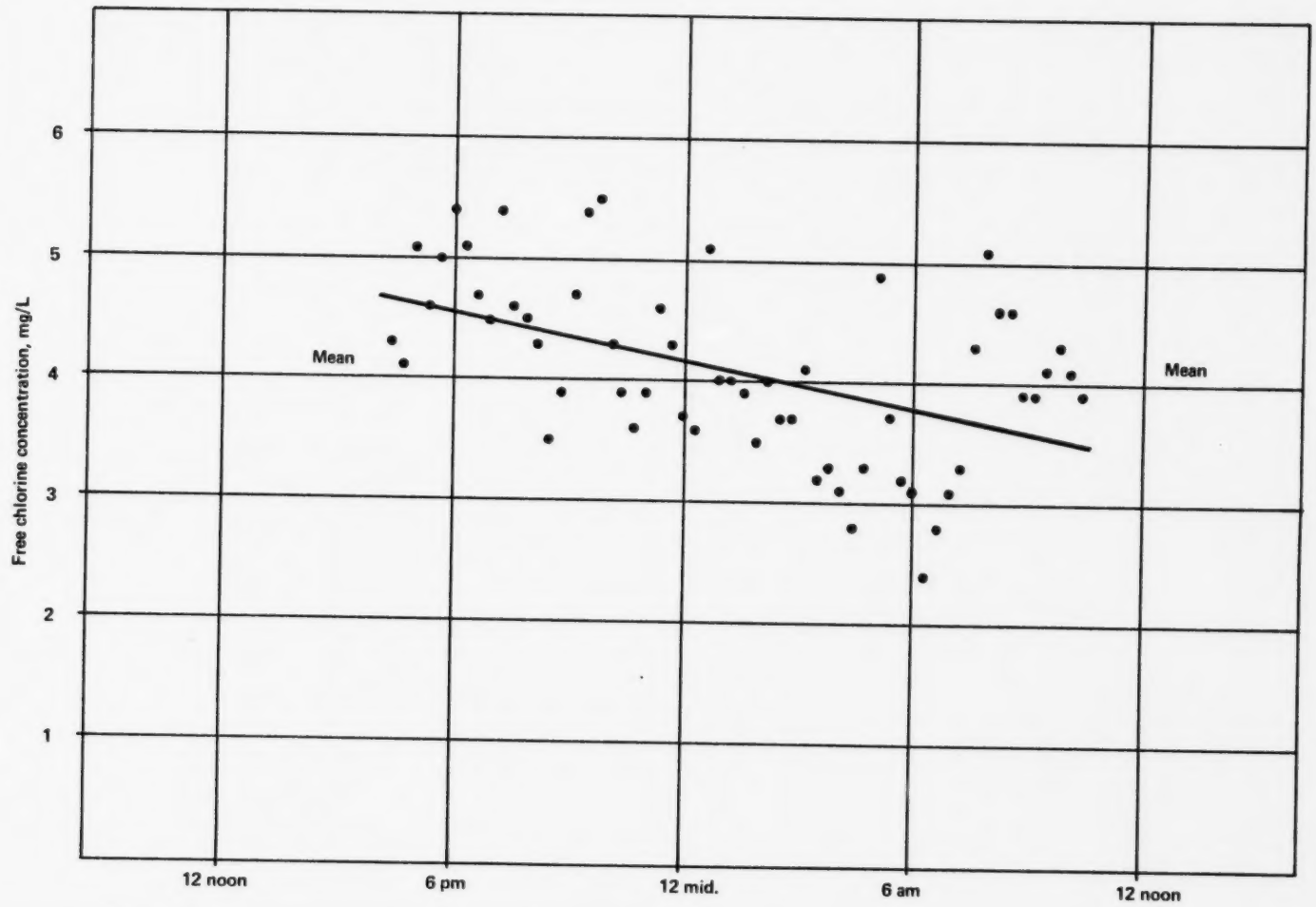

Figure 15. Free chlorine concentrations for intermittent flow at 25 gallons per minute, 10 minutes on, 10 minutes off.

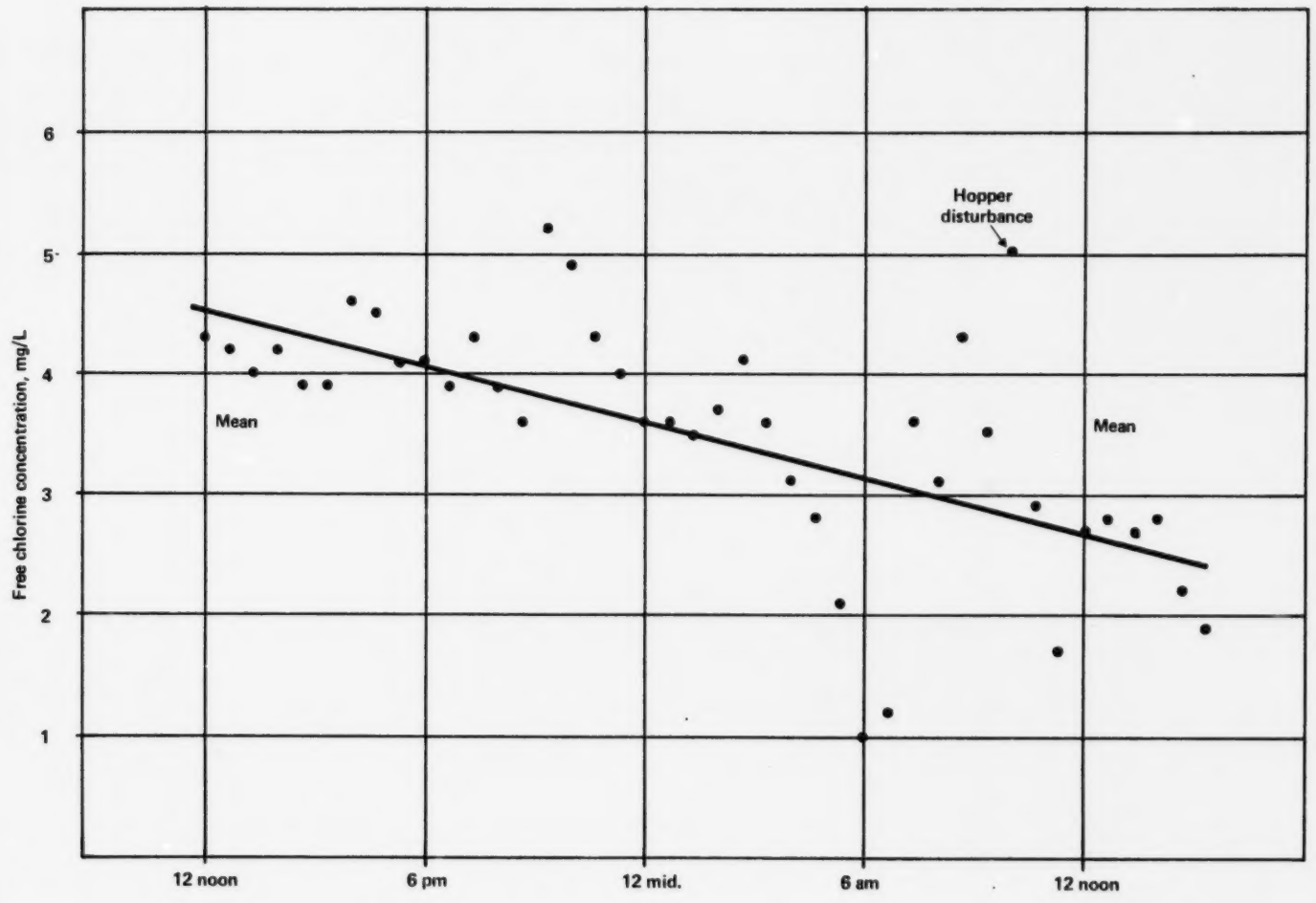

Figure 16. Free chlorine concentrations for intermittent flow at 25 gallons per minute, 10 minutes on, 30 minutes off.

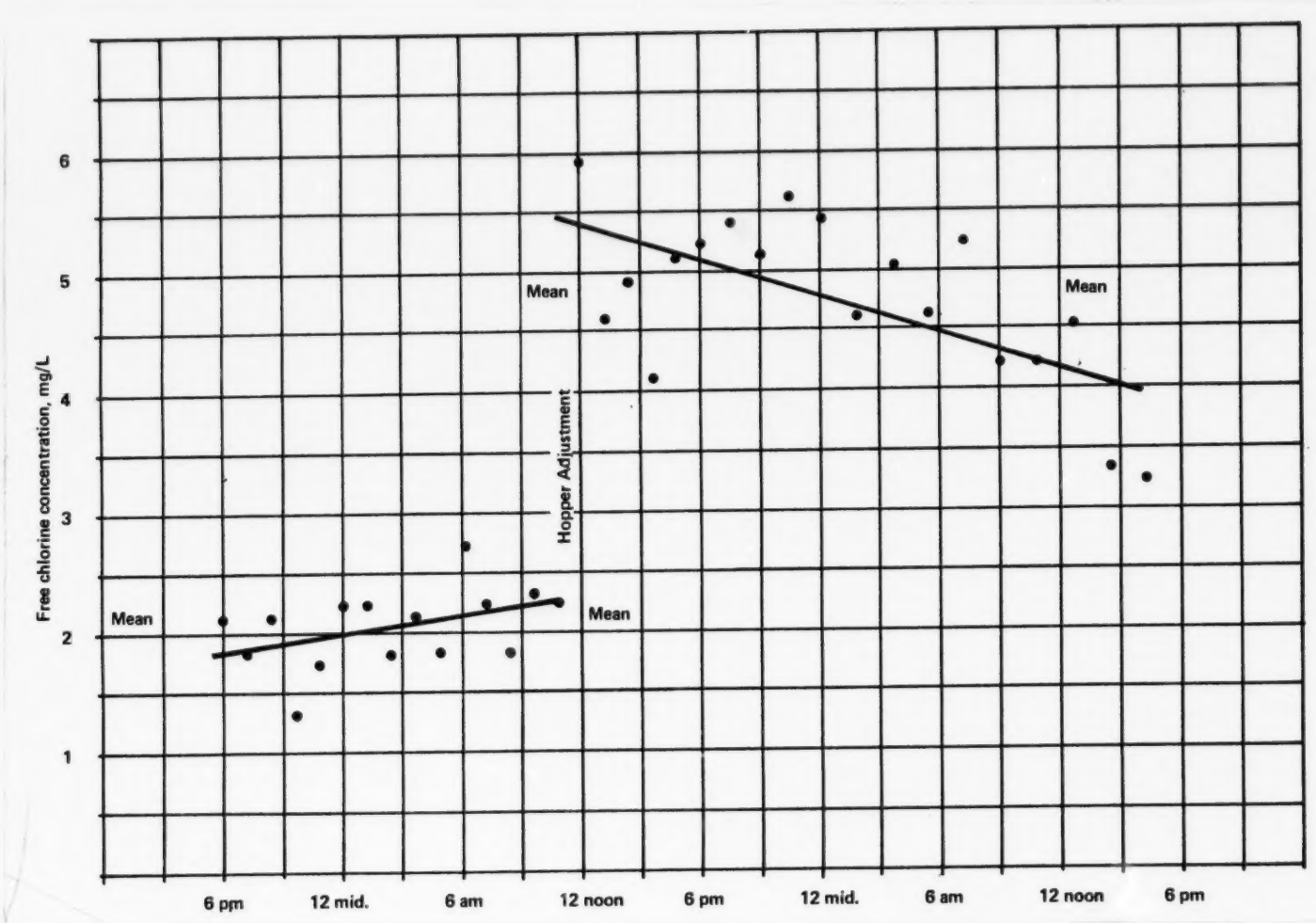

Figure 17. Free chlorine concentrations for intermittent flow at 25 gallons per minute, 10 minutes on, 60 minutes off.

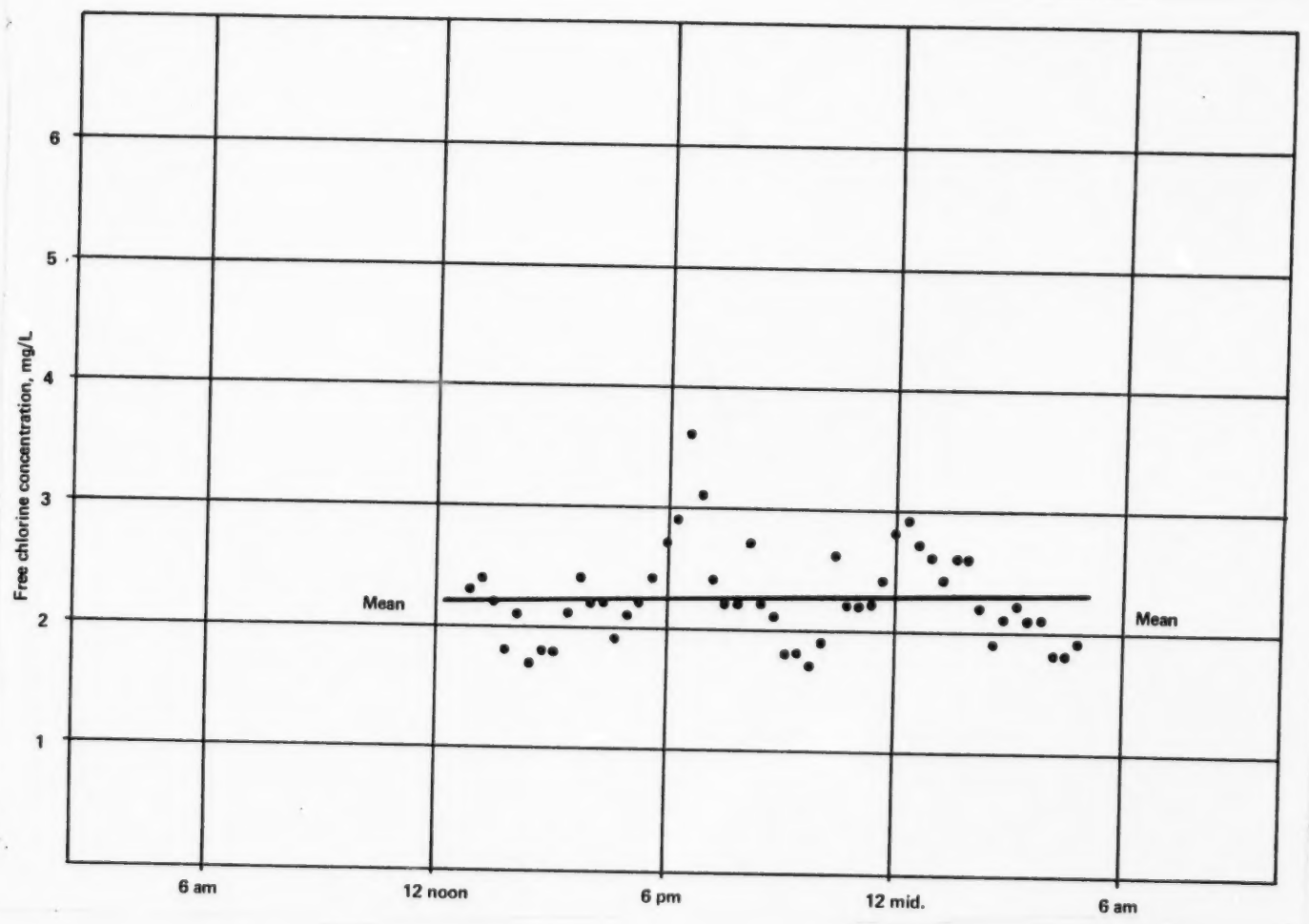

Figure 18. Free chlorine concentrations for intermittent flow at 15 gallons per minute, 10 minutes on, 10 minutes off.

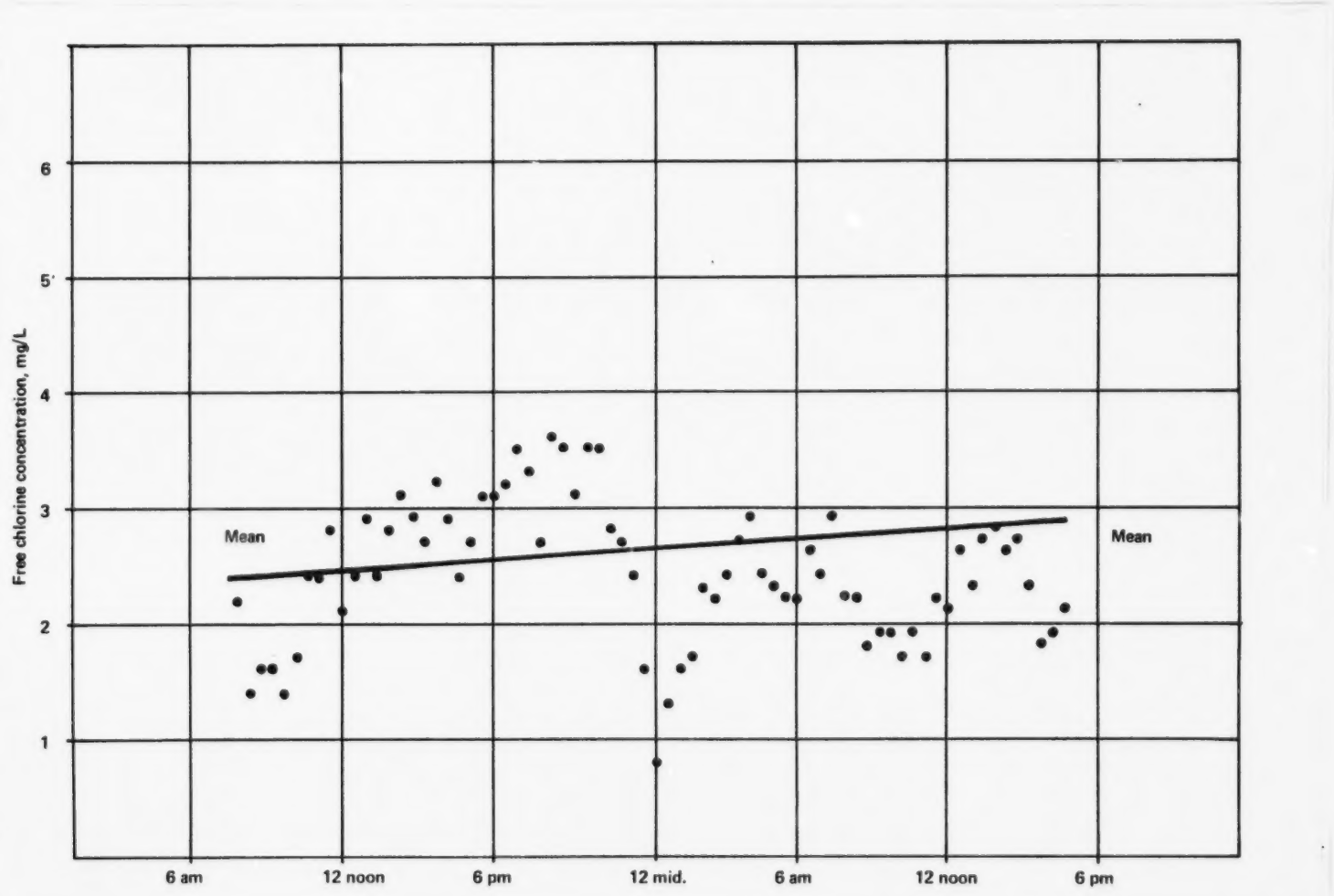

Figure 19. Free chlorine concentrations for intermittent flow at 15 gallons per minute, 10 minutes on, 20 minutes off.

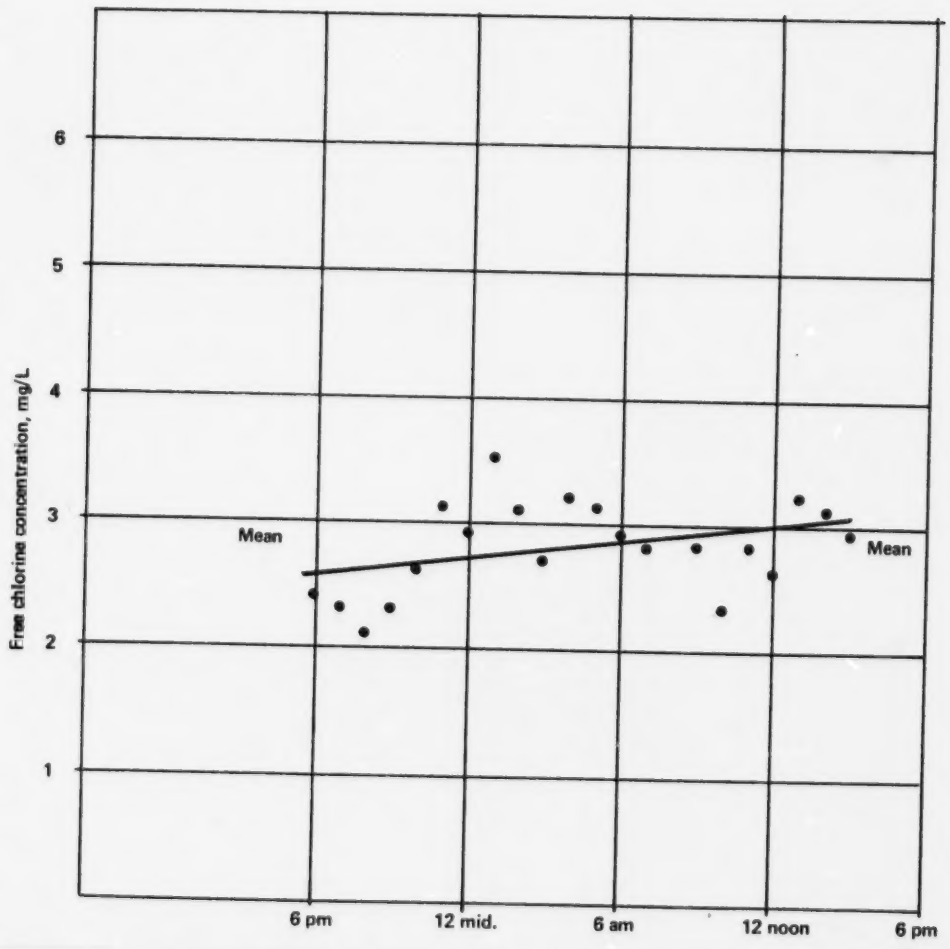

Figure 20. Free chlorine concentrations for intermittent flow at 15 gallons per minute, 10 minutes on, 60 minutes off.

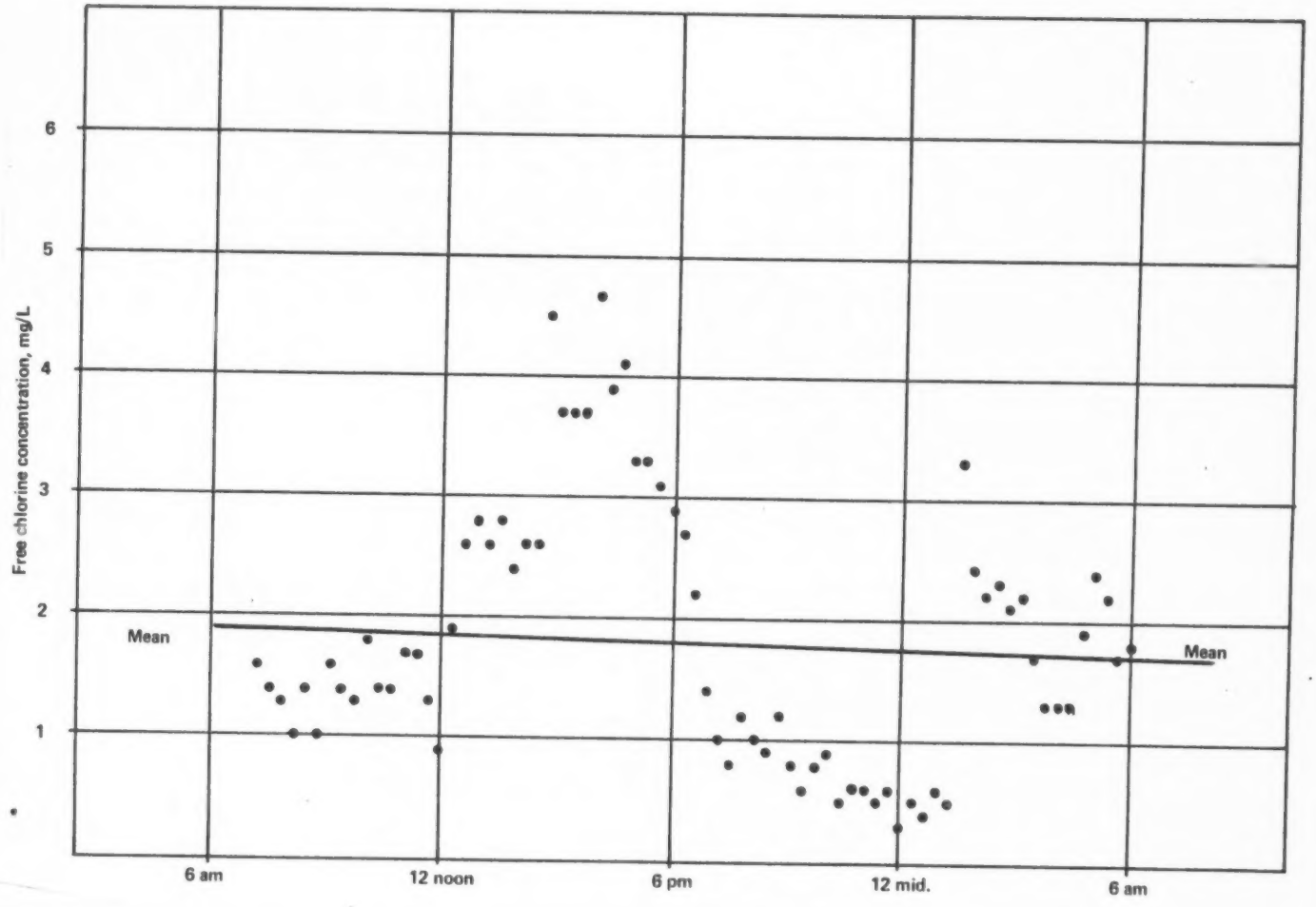

Figure 21a. Free chlorine concentrations for intermittent flow at 7 gallons per minute, 10 minutes on, 20 minutes off.

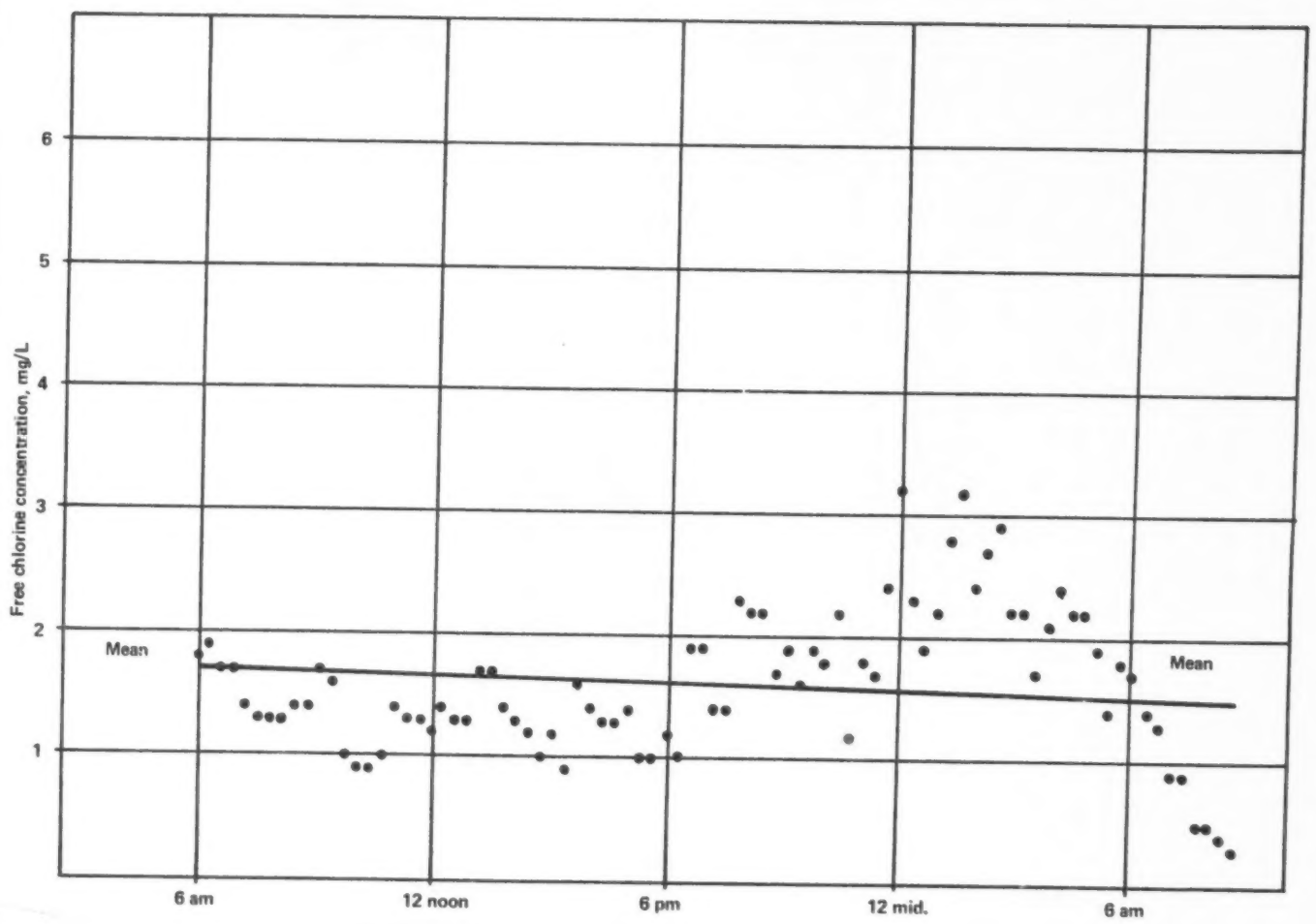

Figure 21b. Free chlorine concentrations for intermittent flow at 7 gallons per minute, 10 minutes on, 20 minutes off.

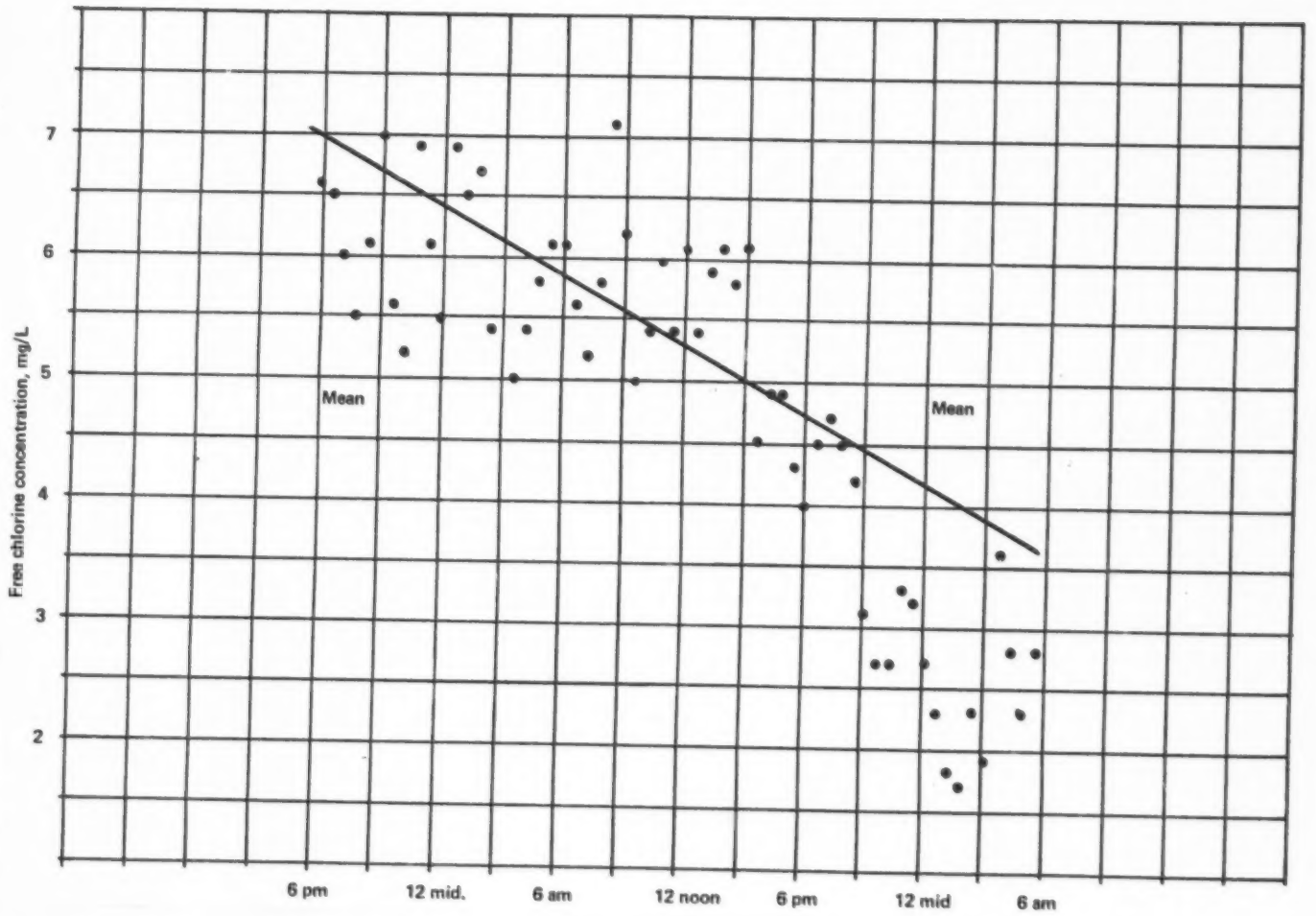

Figure 22. Free chlorine concentrations for intermittent flow at 7 gallons per minute, 10 minutes on, 30 minutes off.

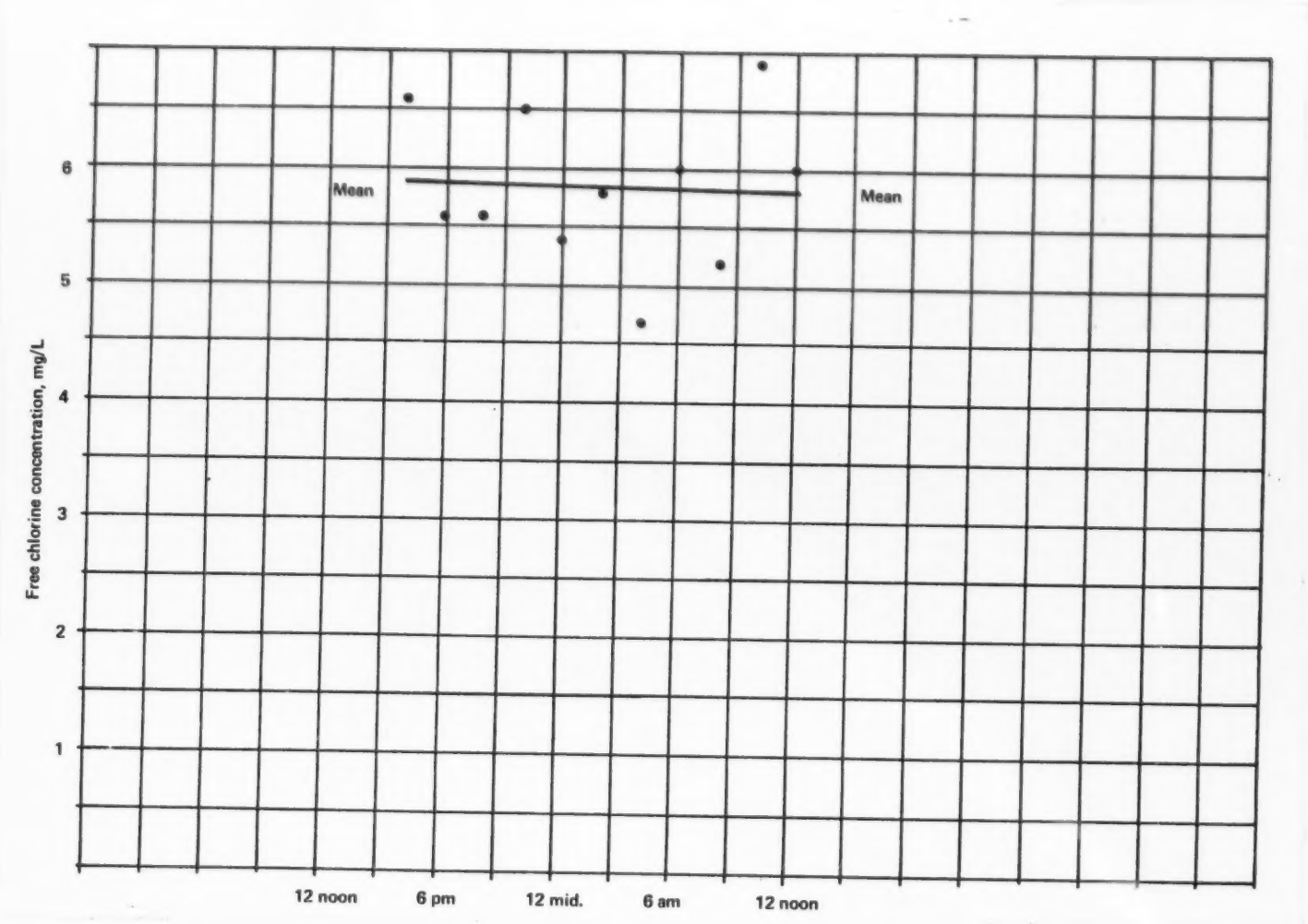

Figure 23. Free chlorine concentrations for intermittent flow at 7 gallons per minute, 10 minutes on, 60 minutes off.

its frequency was less than that during this test phase. Tablet material may also have been dislodged by jarring of the canister at the beginning of each flow cycle. A vibration of the canister was observed at 40 gpm. Its strength, however, was not great and decreased with flow so that it was not detected at 7 gpm.

Testing was planned so that visual observations, as described above, and comparisons of data patterns of individual test segments would reveal any operation patterns. However, uncontrolled humidity levels altered data patterns so that clear, uninterrupted patterns were not available. Although the simultaneous occurrence of variables complicated the evaluation of the impacts of flow and dry periods (off-cycles), it did provide the opportunity to evaluate actual use conditions. Isolated periods of similar humidity levels did provide an indication of flow and off-cycle impacts.

As stated before, the best overall performance of the chlorinator was observed when the flow rate was 40 gpm and the operating cycles were 10-minutes on, 10-minutes off. The effects of humidity, reduced flow, and increased off-cycles resulted in expanded ranges of chlorine concentration fluctuation, with humidity levels providing the greatest impact. The benefits derived from the above operating conditions were, in order of importance, as follows:

- Interrupting the flow reduced moisture levels in the canister.
- A 10-minute off-cycle did not significantly alter conditions in the erosion zone.
- The turbulence (and possibly vibration) at the onset of a 40-gpm flow mitigated the impacts of adverse conditions.

Comparison of the data patterns in Figures 12 through 23 show the impact of changing variables. In evaluating the primary variables, flow and off-cycle, the data were arranged in the following order:

Off-cycle Min	Flow rate, gpm			
	40	25	15	7
		Figure No.		
10	12	15	18	21a/21b
30	13	16	19	22
60	14	17	20	23

Generally, expanded data patterns and erratic chlorine concentrations occurred during periods of high humidity. Data obtained during periods of moderate and low humidity are illustrated in Figures 18, 20, and 23. Additional "dry weather" data also occur in portions of Figures 12, 21a and 21b. Although definitive data patterns for "dry weather" operation are interrupted, sufficient data exist to indicate a relative stability of chlorine doses during intermittent operation of the chlorinator.

Comparisons of data occurring during periods of low humidity indicate the drying of the erosion zone results in expanded fluctuation zones for chlorine concentrations. Decreased flows with a 10-minute off-cycle did not result in a significant degration of dose stability. Similar periods of low humidity occurred during the first 6 hours of Figure 12, the first 4 to 5 hours of Figure 21a, and the first 12 hours of Figure 21b. The respective fluctuation ranges for these data were about 0.4 mg/L, 0.6 mg/L, and 0.8 mg/L. The data occurring during the periods showed stable average concentrations with deviations within acceptable ranges. The data in Figures 20 and 23, however, showed expanded fluctuation spans of 1 mg/L and 1½ mg/L, respectively. Expanding

fluctuation spans were also seen during periods of high humidity when the off-cycle was increased (see Figures 12 through 16).

Increasing the off-cycle resulted in drying of the erosion zone. Although this was expected to be a benefit, it proved otherwise. During the off-cycle, most of the free water quickly drained from the erosion zone. That remaining would have continued to be absorbed by the tablets. After 10 minutes, the moisture conditions in the erosion zone and tablet immediately above were not significantly changed. However, with increased time, drying of the tablet surfaces and loose tablet material became dominant. Since the continued exposure to moisture, followed by drying, increased the amount of loose tablet material, the onset of the next on-cycle would result in increased exposure of calcium hypochlorite surfaces. The amount of loose material present would depend on the amount removed during the previous on-cycle and the rates of moisture absorption and evaporation. With low humidity, these rates should have been fairly constant and fluctuations would be dependent primarily on flow-related turbulence; higher flows should have resulted in a fairly stable dose rate. Low flows would result in the data pattern observed in Figure 23 because the amount of material removed during the onset of flow would be small. Fluctuating amounts of loose tablet material due to cyclic buildup and removal would result in fluctuating chlorine concentrations.

As humidity levels increased, a number of related actions occurred to alter the impact of the off-cycle. Tablets in the upper level of the canister were softened to various degrees, dependent on the humidity. These tablets would have varying initial erosion rates. The amount of moisture absorbed during the off-cycle would increase and the evaporation rate would slow. The impact of this would be dependent on the flow rate. At 40 gpm, the undulating data pattern seen in Figures 13, 14, and 15 were attributed to changes in humidity levels occurring during testing. The changes in chlorine concentration occurring between successive on-cycles were reduced by the turbulence associated with this flow rate. The data patterns were indicative of humidity levels. With reduced flow rates, the data pattern became erratic as seen in the remaining figures. The impact of turbulence was particularly noted in Figures 21a, 21b, and 22. At 7 gpm, the amount of turbulence was insufficient to mitigate the impact of moisture. The data patterns of "wet weather" operation resemble those seen in continuous-flow testing. The results shown in these figures are attributed to the interference of calcium deposition and the same moisture actions seen with continuous-flow. The presence of high humidity results in operating conditions identical to continuous-flow when the flow rate is reduced.

Turbulence at the beginning of each on-cycle tended to improve the performance of the chlorinator by removing loose tablet material and providing relatively uniform calcium hypochlorite surface in the erosion zone. With other conditions remaining equal, the turbulence associated with each flow rate should have removed equal amounts of tablet material and resulted in uniform chlorine concentrations. However, the impact of moisture levels in the tablets resulted in a flow-related benefit from turbulence. As indicated in the discussion above, dose stability was related to both flow rate and the off-cycle period when humidity levels increased. Although turbulence was important to achieving dose stability, its impact was diminished by moisture. If static conditions could be maintained under field conditions, flow rates of 25 and 40 gpm should provide at least acceptable dose stability. A flow rate of 15 gpm might also provide stability, but the reduction of flow results in increasing chlorine concentration fluctuations. The relationship between humidity and turbulence is illustrated by the progressive degration of dose stability seen in the data. Because of the variable conditions encountered during testing, it is clear that a flow rate of 40 gpm is needed to provide suitable chlorinator performance. Also, this flow rate must be accompanied by a short period of flow interruption.

The improved performance of the chlorinator during this test phase was attributed primarily to the interruption of flow through the unit. This permitted the erosion zone to drain, resulting in

decreased exposure of tablets throughout the canister to flow-induced moisture. Draining of the erosion zone not only decreased the time exposure of tablets to moisture but, more importantly, it interrupted the migration of moisture into the upper tablet levels. During continuous-flow testing, elevated moisture levels in the canister were detected even during periods of low humidity when the flow rate was 40 gpm. However, intermittent operation did not result in the flow-related moisture levels seen before. Generally, moisture levels were significantly less than those encountered with continuous operation, and the overall impact of humidity increases was lessened. Tablet bridges were not found during test stand attendance, although data patterns (inverted spikes) did indicate their formation and natural release. Reduced moisture levels in the canister resulted in improved chlorination performance.

Although data patterns for individual test segments showed variations, data on trend lines calculated for the segments showed fairly consistent dose rates. These trend lines also showed humidity and flow-related patterns, but the impact was not severe. During periods of low and moderate humidity, the trend lines showed a virtually flat slope. Except for those occurring at 7 gpm, the slopes of trend lines for periods of higher humidity did not show a great change. "Wet weather" trend lines, however, did not show a consistency in their trend directions; both increasing and decreasing trends were observed.

The trend lines for the various test segments indicate that although dose fluctuations occurred, the long-term average chlorine concentration remained relatively stable. Dose stability can be buffered by water storage time. Although this was not investigated, it appeared that storage tanks (or chlorine contact chambers) providing as little as 2 to 3 hours detention might have provided a sufficient buffer to mitigate dose fluctuations. This is especially indicated with a 40 gpm flow and a 10-10, off-on cycle (Figure 12).

REFERENCES

1. Standard Methods for the Examination of Water and Wastewater. 15th Edition. Washington, D.C.: American Public Health Association, 1981.